PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR THE REMOVAL OF RADIOACTIVE CHEMICAL CONTAMINANTS BY PACKAGED DRINKING WATER TREATMENT SYSTEMS

DRAFT as of February 12, 1999

REQUIREMENTS FOR ALL STUDIES

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Recommended by
The Steering Committee for the Verification of
Package Drinking Water Treatment Systems/Plants
On (insert date)

NSF International

Mission Statement:
NSF International (NSF), an independent, not-for-profit organization, is dedicated to public health safety and protection of the environment by developing standards, by providing education and providing superior third party conformity assessment services while representing the interests of all stakeholders.

NSF Purpose and Organization
NSF International (NSF) is an independent not-for-profit organization. For more than 52 years, NSF has been in the business of developing consensus standards that promote and protect public health and the environment and providing testing and certification services to ensure manufacturers and users alike that products meet those standards. Today, millions of products bear the NSF Name, Logo and/or Mark, symbols upon which the public can rely for assurance that equipment and products meet strict public health and performance criteria and standards.

Limitations of use of NSF Documents
This protocol is subject to revision; contact NSF to confirm this revision is current.
The testing against this protocol does not constitute an NSF Certification of the product tested.

U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program---or ETV---to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and U.S. EPA regions with high quality data on the performance of new technologies. This encourages more rapid availability of approaches to better protect the environment.

ETV s Package Drinking Water Treatment Systems Pilot Project:
Concern about drinking water safety has accelerated in recent years due to much publicized outbreaks of waterborne disease and information linking ingestion of high levels of disinfection byproducts to cancer incidence. The U.S. EPA is authorized through the Safe Drinking Water Act to set numerical contaminant standards and treatment and monitoring requirements that will ensure the safety of public water supplies. However, small communities are often poorly equipped to comply with all of the requirements; less costly package treatment technologies may offer a solution. These package plants can be designed to deal with specific problems of a particular community; additionally, they may be installed on site more efficiently---requiring less start-up capital and time than traditionally constructed water treatment plants. The opportunity for the sales of such systems in other countries is also substantial.

The U.S. Environmental Protection Agency (EPA) has partnered with NSF, a nonprofit testing and certification organization, to verify performance of small package drinking water systems that serve small communities. It is expected that both the domestic and international markets for such systems are substantial. EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, and states (issuers of permits), to assist in formulating consensus testing protocols. A goal of verification testing is to enhance and facilitate the acceptance of small package drinking water treatment equipment

by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment use is contemplated. NSF will meet this goal by working with equipment Manufacturers and other agencies in planning and conducting equipment verification testing, evaluating data generated by such testing and managing and disseminating information. The Manufacturer is expected to secure the appropriate resources to support their part of the equipment verification process, including provision of equipment and technical support.

The verification process established by EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process is a model process that can help in moving small package drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a verification/Field Operations Document;
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;
4. Performance and cost (labor, chemicals, energy) verification;
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF International with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. NSF's role is to provide technical and administrative leadership and support in conducting the testing. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Partnerships:
The U.S. EPA and NSF International (NSF) are cooperatively organizing and developing the ETV's Package Drinking Water Treatment Systems Pilot Project to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators have an understanding to assist each other in promoting and communicating the benefits and results of the project.

ORGANIZATION AND INTENDED USE OF PROTOCOL AND TEST PLANS

NSF encourages the user of this protocol to also read and understand the policies related to the verification and testing of package drinking water treatment systems and equipment.

The first Chapter of this document describes the Protocol required in all studies verifying the performance of equipment or systems removing radioactive chemical contaminants, the public health goal of the Protocol. The remaining chapters describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the Protocol: the removal of radioactive chemical contaminants.

Prior to the verification testing of a package drinking water treatment systems, plants and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified, Field Testing Organization. This designated Field testing Organization must write a "Field Operations Document". The equipment manufacturer and/or supplier will need this protocol and the test plans herein and other NSF Protocols

and Test Plans to develop the Field Operations Document depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or test plan may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified, Field Testing Organization that is selected by the Manufacturer. Water quality analytical work to be completed as a part of an NSF Equipment Verification Testing Plan shall be contracted with a state or EPA-qualified laboratory. For information on a listing of NSF-qualified field testing organizations, contact NSF International.

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CHAPTER 1

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR THE REMOVAL OF RADIOACTIVE CHEMICAL CONTAMINANTS BY PACKAGED DRINKING WATER TREATMENT SYSTEMS

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LIST OF ABBREVIATIONS

EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
FOD	Field Operations Document
gpm/sf	gallons per minute per square foot
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
NSF	NSF International
PE	performance evaluation
pCi/L	Picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
rpm	revolutions per minute
% RSD	percent relative standard deviation
SDWA	Safe Drinking Water Act
WSWRD	Water Supply and Water Resources Division

1.0 INTRODUCTION

This document is the study protocol that will be used for Verification Testing of equipment designed to achieve removal of radioactive chemical contaminants (radionuclides). This protocol may be applicable to various types of water treatment equipment capable removal of radionuclides. Equipment testing may be undertaken to verify performance of a packaged plant systems employing processes that may include but are not limited to cation and anion exchange resins, zeolites, adsorptive media, reverse osmosis membranes, and air stripping for the removal of radionuclides. The specific radionuclide to be targeted for removal during Verification Testing shall be clearly identified in the Field Operations Document (FOD) prior to the initiation of testing by the Field Testing Organization (FTO). The FOD may include more than one Testing Plan; however, the FTO must adhere to the specific minimum requirements of each study protocol in developing a FOD. The final submission of the FOD shall:

- Include the information requested in this protocol.
- Conform to the format identified in this protocol.
- Conform to the specific NSF International (NSF) Equipment Verification Testing Plan or Plans related to the Statement or Statements of Capabilities that are to be verified.

The United States Environmental Protection Agency (EPA) has partnered with NSF International (NSF), a non-profit testing and certification organization, to conduct an Environmental Technology Verification (ETV) Project that will verify performance of innovative technical solutions to problems that affect human health or the environment in small systems. To accelerate the introduction of these innovative technologies a verification protocol and testing plan were developed to verify these small packaged drinking water systems that serve small communities.

Emphasis of the ETV is on the performance and cost factors of specific package plants that address common small system contaminants (i.e., microbials, radioactive chemicals, particulates, disinfection by-products, and organic and inorganic chemicals). EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, consulting engineers and State permitters, to assist in formulating consensus-testing protocols. A goal of Verification Testing is to enhance and facilitate the acceptance of small packaged drinking water treatment equipment by State drinking water regulatory engineers and consulting engineers while reducing the need for testing of equipment at each location where the equipment use is contemplated. In turn these testing plans will produce a data base following the verification protocol format from which package plants can be designed to deal with specific water quality issues and may be installed on-site more efficiently.

NSF will meet this goal by working with equipment Manufacturer Field Testing Organizations and other agencies in planning and conducting Equipment Verification Testing Projects, evaluating data generated by such testing and managing and disseminating information. The Manufacturer is expected to secure the appropriate resources to support their part of the equipment verification process, including provision of equipment and technical support.

The verification process established by EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process is a model process that can help in moving small packaged and/or modular drinking water treatment equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a verification/FOD.
2. Execution of Verification Testing.
3. Data reduction, analysis, and reporting.
4. Cost and performance (labor, chemicals, energy) verification.
5. Report preparation and information transfer.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the FTO may find useful in preparation of the FOD. *The italicized text indicates specific study protocol deliverables that are required of the FTO or the Manufacturer and that must be incorporated in the FOD.*

The following glossary terms are presented here for subsequent reference in this protocol:

- **Certification** - The attestation that a piece of equipment and/or a device has met all applicable requirements, (e.g., standard performance criteria and policies), and continues to meet all applicable requirements.
- **Company** - Any public or private organization, group, individual, or other entity contracting with NSF, or a subsidiary or division of such an entity.
- **Distribution System** - A system of conduits by which a primary water supply is conveyed to consumers, typically by a network of pipelines.
- **EPA** - The United States Environmental Protection Agency, its staff or authorized representatives.
- **Equipment** – Testing equipment for use in the Verification Testing Program, which may be, defined as either a package plant or modular system.
- **Manufacturer** - A business that assembles and/or sells package plant equipment and/or modular systems. The role of the Manufacturer is to provide the package plant and/or modular system and technical support during the Verification Testing Program. The Manufacturer is also responsible for providing assistance to the third party FTO during operation and monitoring of the package plant or modular system during the Verification Testing Program.
- **Field Operations Document (FOD)** - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.
- **Field Testing Organization (FTO)** - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the FTO is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; arrange for or conduct the skilled operation of a package plant during the intense periods of testing during the study and the tasks required by the Protocol.
- **Modular System -** A packaged functional assembly of components for use in a drinking water treatment system or packaged plant that provides a limited form of treatment of the feedwater(s) and which is discharged to another packaged plant or the final step of treatment to the distribution system.

- **NSF** - NSF International, its staff, or other authorized representatives
- **NSF Equipment Verification Testing Plan** - A specific testing plan for each packaged plant technology application, such as systems employing cation and anion exchange, adsorptive media, reverse osmosis, and air stripping for the removal of radioactive chemical contaminants. This plan will be developed by NSF for the Manufacturer to assist in development of the FOD for the Verification Testing Program.
- **Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) through discharge to the distribution system.
- **Plant Operator** - The person working for a small water system who is responsible for operating package water treatment equipment to produce treated drinking water. This person may also collect samples, record data and attend to the daily operations of equipment throughout the testing periods.
- **Preferred Qualified Field Testing Organization** - One meeting all required qualifications, meeting at least one of the secondary qualifications, and meeting ANSI/ASQC E4-1994 or having a plan to meet ANSI/ASQC E4-1994 within six months.
- **Protocol** - A written document that clearly states the objectives, goals and scope of the study as well as the test plan(s) for the conduct of the study. The protocol shall be used for reference during Manufacturer participation in the Verification Testing Program.
- **Provisionally Qualified Field Testing Organization** - One having identified deficiencies, but demonstrates its ability to conduct valid Verification Testing of package plants and modular systems.
- **Qualified Field Testing Organization** - One meeting all applicable NSF requirements.
- **Report** - A written document that includes data, test results, findings, and any pertinent information collected in accordance with a protocol, analytical methods, procedures etc., in the assessment of a product whether such information is in preliminary, draft or final form.
- **Study Protocol for Equipment Verification Testing** - This document. The protocol will be used for reference during Manufacturer participation in Verification Testing Program.
- **Testing Organization** - An organization qualified to perform studies and testing of package or modular systems. The role of the testing organization is to ensure that there is skilled operation of a package plant during the intense periods of testing and that all of the tasks required by the Study Protocol for Equipment Verification Testing are performed properly. The Testing Organization is responsible for:
  - ⇒ Managing, evaluating, interpreting and reporting on the data produced by the Verification Testing Program.
  - ⇒ Providing logistical support, scheduling and coordinating the activities of all participants in the Verification Testing Program, i.e., establishing a communications network.
  - ⇒ Advising the Manufacturer on feedwater quality and test site selection, such that the locations selected for the Verification Testing Program have feedwater quality consistent with the objectives of the Study Protocol for Equipment Verification Testing.
- **Testing Plan** - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the test plan will

include detailed instructs for sample and data collection, sample handling and sample preservation, precision, accuracy, and reproducibility goals, and quality assurance and quality control requirements.

- **Testing Laboratory** - An organization certified by a third- party independent organization, Federal agency, or a pertinent State regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the Verification Testing of package plants and/or modular systems is to analyze the water samples in accordance with the methods and meet the pertinent quality assurance and quality control requirements described in the protocol, test plan, and FOD.
- **Verification** - To establish the evidence on the range of performance of equipment and/or device under specific conditions following a predetermined study protocol(s) and test plan(s).
- **Verification Statement** - A written document that summarizes a final report reviewed and approved by NSF on behalf of the EPA or directly by the EPA.
- **Water System** - The water system that operates using packaged water treatment equipment to provide potable water to its customers.

1.1 Objectives

The specific objectives of the Equipment Verification Testing Project may be different for each package plant or modular system, depending upon the Statement of Capabilities of the specific equipment to be tested. The objectives developed by each Manufacturer will be defined and described in detail in the FOD developed for each piece of equipment. The objectives of the Equipment Verification Testing Project may include but are not limited to the following:

- Generation of field data appropriate for verifying the performance of the equipment.
- Generation of field data in support of meeting current National Primary Drinking Water Standards, the EPA National Secondary Drinking Water Standards, and/or anticipated water quality regulations. (Note that compliance with Drinking Water Standards or regulations is not necessarily a primary objective of equipment Verification Testing.)
- Generation of operation and maintenance information to assist users and potential operators of equipment.
- Evaluation of new advances in equipment and equipment design.

An important aspect in the development of Verification Testing is to describe the procedures that will be used to verify the Statement of Performance Capabilities made for water treatment equipment. A Verification Testing plan document shall incorporate the quality assurance/quality control (QA/QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Although Verification Testing conducted at a single site may not represent every environmental situation that may be acceptable for the equipment tested, it will provide data of sufficient quality to make a judgment about the application of the equipment under conditions similar to those encountered in the verification testing. A Quality Assurance Project Plan (QAPP) shall be described in detail and provided as part of the FOD.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

1.2 Scope

This protocol outlines the verification process for equipment designed to achieve removal of radionuclides. This protocol can be used in conjunction with a number of different testing plans for package and/or modular drinking water treatment systems designed to achieve removal of radionuclides. This protocol is not a NSF or third party consensus standard and it does not endorse the packaged plants or technologies described herein.

An overview of the equipment verification process and the elements of the FOD to be developed by the Manufacturer are described in this protocol document. Specifically, the FOD shall define the following elements of the Verification Testing:

- Roles and responsibilities of Verification Testing participants.
- Procedures governing Verification Testing activities such as: equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation.
- Experimental design of the Field Operations Procedures. The Field Operations Procedures will identify recommended equipment maintenance and cleaning methods.
- Quality assurance (QA) and quality control (QC) procedures for conducting the Verification Testing and for assessing the quality of the data generated from the Verification Testing.
- Health and safety measures relating to biohazard, electrical, mechanical and other safety codes.

Content of FOD Regarding Verification Testing Objectives and Scope

The structure of the FOD must conform to the outline below: The required components of the Document will be described in greater detail in the sections below.

- *TITLE PAGE*
- *FOREWORD*
- *TABLE OF CONTENTS The Table of Contents for the FOD should include the headings provided in this document although they may be modified as appropriate for a particular type of equipment to be tested.*
- *LIST OF DEFINITIONS - A list of key terms used in the FOD should be provided*
- *EXECUTIVE SUMMARY - The Executive Summary describes the contents of the FOD (not to exceed two pages). A general description of the equipment and the Statement of Performance Capabilities which will be verified during testing as well as the testing locations, a schedule, and a list of participants.*
- *ABBREVIATIONS AND ACRONYMS A list of the abbreviations and acronyms used in the FOD should be provided.*

- *EQUIPMENT VERIFICATION TESTING RESPOSIBILITIES(Section 2)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (Section 3)*
- *EXPERIMENTAL DESIGN (Section 4)*
- *FIELD OPERATIONS PROCEDURES (Section 5)*
- *QUALITY ASSURANCE TESTING PLAN (Section 6)*
- *DATA MANAGEMENT AND ANALYSIS (Section 7)*
- *SAFETY PLAN (Section 8)*

2.0 EQUIPMENT VERIFICATION TESTING RESPOSIBILITIES

2.1 Verification Testing Organization and Participants

This Verification Testing Project is being conducted by NSF International with participation of Manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. The WSWRD and NSF jointly are administering the Equipment Verification Testing Program. NSF's role is to provide technical and administrative leadership and support in conducting the testing.

The required content of the FOD and the responsibilities of participants are listed at the end of each section. In the development of a FOD, Manufactures and their designated FTO shall provide a table including

- the name, affiliation, and mailing address of each participant;
- a point of contact;
- description of participant's role;
- telephone and fax numbers; and
- e-mail address.

The equipment provided by the Manufacturer shall explicitly meet all requirements of Occupational Safety and Health Association (OSHA), NEMA, Underwriters Laboratory (UL), NSF and other appropriate agencies in order to ensure operator safety during Verification Testing.

2.2 Verification Testing Agreement

After equipment has been accepted by NSF into the Environmental Technology Verification Program (ETV), a letter agreement will be signed between the Manufacturer and the NSF. The purpose of the agreement is to specify a framework of responsibilities for conducting the ETV. It is important to note that the Manufacturer and the NSF must approve the entire FOD, including a Quality Assurance Project Plan (QAPP), before the Verification Testing can proceed.

2.3 Organization

The organizational structure for the Verification Testing showing lines of communications shall be provided by the FTO in its application on behalf of the Manufacturer.

2.4 Verification Testing Site Name and Location

This section discusses background information on the Verification Testing site(s), with emphasis on the quality of the feedwater, which in some cases may be the source water at the site. The FOD must provide the site names and locations at which the equipment will be tested. In most cases, the equipment will be demonstrated at more than one site. Depending upon the Verification Testing requirements stipulated in the Testing Plan employed, testing of the equipment may be required under different conditions of feedwater quality (or source water quality) that allow evaluation of system performance over a range of seasonal climate and weather conditions.

2.5 Site Characteristics

The FOD must include a description of the test site. This shall include a description of where the equipment will be located. If the feed water to the packaged plant equipment is the source water for an existing water treatment plant, describe:

- the raw water intake;
- the opportunity to obtain raw water without the addition of any chemicals; and
- the operational pattern of raw water pumping at the full-scale facility (is it continuous or intermittent?).

The source water characteristics shall be described and documented. The FOD shall also describe facilities to be used for handling the treated water and wastes (i.e., residuals) produced during the Verification Testing Program. The FOD will state whether the required water flows and waste flows produced are dealt with in an acceptable way, and whether any water pollution discharge permits are needed.

2.6 Responsibilities

The FOD shall identify the organizations involved in the testing and describes the primary responsibilities of each organization. Multiple Manufacturer testing for removal of radionuclides may be conducted concurrently, and be fully in compliance with the NSF Equipment Verification Testing Program. The responsibilities of the Manufacturer will vary depending on the type of Verification Testing. However, at a minimum, the Manufacturer shall be responsible for:

- Providing the equipment to be evaluated during Verification Testing. The equipment must be in complete working order at delivery to the test site.
- Provide equipment that explicitly meets all requirements of OSHA, NEMA, UL, NSF and other appropriate agencies in order to ensure operator safety during Verification Testing.

The FTO shall be responsible for:

- Providing needed logistical support, establishing a communication network, and scheduling and coordinating the activities of all Verification Testing participants.
- Advising the Manufacturer on feedwater quality and test site selection, such that the locations selected as test sites have feedwater quality consistent with the objectives of the Verification Testing (The Manufacturer may recommend a site for Verification Testing.)
- Managing, evaluating, interpreting, and reporting on data generated by the Verification Testing.
- Evaluating and reporting on the performance of the technologies applied to achieve removal of radionuclides.

Content of FOD Regarding Equipment Verification Testing Responsibilities:

The Manufacturer shall be responsible for:

- *Provision of complete, field-ready equipment for Verification Testing.*
- *Provision of logistical, and technical support, as required.*
- *Provision of technical assistance to the qualified testing organization during operation and monitoring of the equipment undergoing Verification Testing.*

The FTO shall be responsible for including the following elements in the FOD:

- *Definition of the roles and responsibilities of appropriate Verification Testing participants.*
- *A table, which includes the name, affiliation, and mailing address of each participant, a point-of-contact, their role, telephone and fax numbers, and e-mail address.*
- *Organization of operational and analytical support.*
- *List of the site name(s) and location(s).*
- *Description of the test site(s), the site characteristics and identification of where the equipment will be located.*

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities

For this Verification Testing, the Manufacturer and their designated FTO shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. In conjunction with a Statement of Performance Capabilities, the FTO shall state the pertinent detection limits for the specific radionuclide analytical method. Statements should be made regarding the applications of the equipment, the known limitations of he equipment and under what conditions the equipment is likely to fail or underperform. The FTO on behalf of the Manufacturer shall also provide information as to what advantages the Verification Testing equipment provides over existing equipment. The Statement of Performance

Capabilities must be specified and verifiable by a statistical analysis of the data. There are two different types of Statements of Performance Capabilities that may be verified in this testing. Examples include to statements shown in Table 3.1:

Table 3.1: Example Statements of Performance Capabilities for Radionuclide Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Radionuclide Removal	This packaged plant is capable of achieving 90 percent removal of radium during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.
Regulatory Compliance	This packaged plant is capable of producing a product water meeting the National Primary Drinking Water Standards for radium concentration during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.

An example of a Statement of Performance Capabilities that would not be acceptable is presented below:

> "This packaged plant will achieve removal of radionuclides in accordance with the Safe Drinking Water Act (SDWA) on a consistent and dependable basis."

The Manufacturer shall identify the water quality objectives to be achieved in the Statement of Performance Capabilities of the equipment to be evaluated in the verification testing. For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided:

- Applications of the equipment;
- Known limitations of the equipment;
- Advantages it provides over existing equipment;
- Percent removal of the targeted radionuclide;
- Rate of treated water production (i.e., flux);
- Product water recovery;
- Feed stream water quality regarding pertinent water quality parameters;
- Temperature;
- Concentration of targeted radionuclide; and

- Other pertinent water quality and operational conditions.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities. The following equation shall be used to determine percent removal of the radionuclides investigated:

$$\%\ \text{Radionuclide Removal} = 100 * \left[\frac{C_{\text{feed}} - C_{finished}}{C_{feed}} \right]$$

where:

C_{feed} = concentration of radionuclide in the feedwater; and

$C_{finished}$ = concentration of radionuclide in the finished water.

The FTO on behalf of the Manufacturer shall be responsible for identification of which radionuclide shall be monitored and recorded for testing under the Statement of Performance Capabilities in the FOD. The analysis of radionuclides in the feedwater, treated water and wastewater streams shall be performed by a State-certified, third-party accredited or EPA-accredited laboratory using an approved Standard Method.

The Statement of Performance Capabilities prepared by the FTO (in collaboration with the Manufacturer) shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater. Statements of Performance Capabilities that are not too easily met may not be of interest to the potential user, while performance capabilities that are overstated may not be achievable. If a manufacturer relies on integrated processes for radionuclide removal, the Statement of Performance Capabilities must include the overall packaged and/or modular water treatment system radionuclide removal performance. The Statement of Performance Capabilities forms the basis of the entire Equipment Verification Testing Program and must be chosen appropriately. Therefore, the design of the FOD should include a sufficient range of feedwater quality to permit verification of the Statement of Performance Capabilities.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the Radionuclide Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Protocol and the associated Verification Testing Plans are oriented towards removal of radionuclides from feedwaters, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

3.2 Equipment Description

Description of the equipment for Verification Testing shall be included in the FOD. Data plates shall be permanent and securely attached to each production unit. The data plate shall be easy to read in English or the language of the intended user, located on the equipment where it is readily accessible, and contain at least the following information:

a. Equipment Name

b. Model Number

c. Manufacturer's name and address

d. Electrical requirements - volts, amps, hertz and phase

e. Equipment size and weight

f. Shipping requirements and special handling precautions

g. Equipment maintenance requirements

h. Serial Number

i. Warning and Caution statements in legible and easily discernible print size

j. Capacity or output rate (if applicable)

In addition, the Manufacturer must provide the equipment with all OSHA required safety devices (if applicable).

Content of FOD Regarding Equipment Capabilities and Description:

The Manufacturer shall be responsible for:

- *Provision of complete, field-ready equipment with the following information explicitly provided: Equipment Name, Model number, Manufacturer s name and address, electrical requirements (e.g., volts, amps, hertz and phase), equipment size and weight, shipping requirements and special handling precautions, equipment maintenance requirements, Serial number, warning and caution statements in legible and easily discernible print size, capacity or output rate (if applicable).*
- *Provision of equipment complete with all OSHA required safety devices (e.g., safety shields or shrouds, emergency shut-off switches, etc.) for Verification Testing.*

The FTO shall be responsible for including the following elements in the FOD:

- *Description of the equipment to be demonstrated including photographs from several perspectives.*
- *Brief introduction and discussion of the engineering and scientific concepts on which the radionuclide removal capabilities of the water treatment equipment are based.*
- *Description of the package treatment plant and each process included as a component in the modular system including all relevant schematics of treatment and pretreatment systems.*
- *Brief description of the physical construction/components of the equipment, including the general environment requirements and limitations, required consumables; weight, transportability, ruggedness, power and other pertinent information needed, etc.*
- *Statement of typical rates of consumption of chemicals, a description of the physical and chemical nature of wastes, and the rates of waste generation (concentrates, residues, waste products, required regeneration frequencies; materials replacement frequencies; etc.).*
- *Definition of the performance range of the equipment.*
- *Identification of any special licensing requirements associated with the operation of the equipment.*
- *Description of the applications of the equipment and the removal capabilities of the treatment system relative to existing equipment. Comparisons shall be provided in such areas as: treatment capabilities, requirements for chemicals and materials, power, labor*

requirements, suitability for process monitoring and operation from remote locations, ability to be managed by part-time operators.

- *Discussion of the known limitations of the equipment. The following operational details shall be included: the range of feedwater quality suitable for treatment with the equipment, the upper limits for concentrations of regulated contaminants that can be removed to concentrations below the MCL, level of operator skill required to successfully use the equipment.*

4.0 EXPERIMENTAL DESIGN

This section discusses the objectives of the Verification Testing, factors that must be considered to meet the performance objectives, and the statistical analysis and other means that the FTO will use to evaluate the results of the Verification Testing.

4.1 Objectives

The objectives of this Verification Testing are to evaluate equipment in the following areas:

1. Performance relative to the Manufacturer's stated range of radionuclide removal capabilities and equipment operation.
2. Performance relative to radionuclide action levels, and as applicable, any maximum contaminant levels (MCLs) stipulated by the National Primary Drinking Water Standards and the EPA National Secondary Drinking Water Regulations or other specific or anticipated water quality regulations (if desired by the Manufacturer and FTO).
3. The impacts of variations in feedwater quality (such as temperature, pH, alkalinity, etc.) on equipment performance.
4. The logistical, human, and economic resources necessary to operate the equipment.
5. The reliability, ruggedness, cost factors, range of usefulness, and ease of operation.

The FOD provided by the FTO shall include those treatment tests listed in NSF test plans that are most appropriate to challenge the removal capabilities of the equipment for the selected inorganic constituents. For example, if equipment were only intended for removal of radon, there would be no need to conduct testing to evaluate the removal of hydrogen sulfide or carbon dioxide. However, it should be noted that many of the packaged and/or modular drinking water treatment systems participating in the Radionuclide Removal Verification Testing Program might be capable of achieving multiple water treatment objectives. The Verification Testing Program may for example be undertaken to demonstrate equipment removal capabilities for a wide number of constituents. In addition, the FTO and the Manufacturer may wish to construct the FOD so that Verification Testing may also demonstrate the treatment system's removal capabilities and treatment operations for additional water quality parameters. The incorporation of additional treatment objectives may also necessitate attention to the other applicable protocol and test plan documents in the development of the FOD.

4.2 Equipment Characteristics

This section discusses equipment characteristics or factors that will be considered in the design and implementation of the Equipment Verification Testing Program. These factors include:

- ease of operation;
- degree of operator attention required;
- response of equipment and treatment process to changes in feedwater quality;
- electrical requirements;
- system reliability features including redundancy of components;
- feed flow requirements;
- discharge requirements;
- spatial requirements of the equipment (footprint);
- unit processes included in treatment train;
- chemicals needed;
- chemical hazards associated with equipment operation; and
- response of treatment process to intermittent operation.

Verification testing procedures shall simulate routine conditions as much as possible and in most cases testing may be done in the field. Under such circumstances, simulation of field conditions would not be necessary.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impossible to quantify. These are considered qualitative factors. Important factors that cannot easily be quantified are the modular nature of the equipment, the safety of the equipment, the portability of equipment, and the logistical requirements necessary for using it.

Typical qualitative factors to be discussed are listed below, and others may be added. The FOD shall discuss those factors that are appropriate to the test equipment.

- Reliability or susceptibility to environmental conditions
- Equipment safety
- Effect of operator experience on results
- Effect of operator's technical knowledge on system performance and robustness of operation

4.2.2 Quantitative Factors

Many factors of the equipment characteristics can be quantified by various means in this Verification Testing Program. Some can be measured while others cannot be controlled. Typical quantitative

factors to be discussed are listed below, and others may be added. The FOD shall discuss those factors that are appropriate to the test equipment.

- Power and consumable supply (such as chemical and materials) requirements
- Cost of operation, expendables and waste disposal
- Hydrodynamics of packaged plant system
- Length of operating cycle
- Daily labor hours required for operation and maintenance

These quantitative factors will be used as an initial benchmark to assess equipment performance.

4.3 Water Quality Considerations

The primary treatment goal of the equipment employed for Verification Testing through this protocol is to achieve removal of radionuclides found in raw waters such that finished waters are of acceptable water quality. Depending upon the goals of the equipment Manufacturer, the driving force for Verification Testing of radionuclide removal under a specific set of operating and feedwater quality conditions. The objectives of Verification Testing may also be to achieve compliance with the National Primary Drinking Water Standards and the EPA National Secondary Drinking Water Regulations in many cases, and assure production of water with palatable, healthful and consistent water quality. The experimental design and Statement of Performance Capabilities in the FODs shall be developed so the relevant questions about water treatment equipment capabilities can be answered.

Manufacturers should carefully consider the capabilities and limitations of their equipment and prepare FODs that sufficiently challenge their equipment. The FTO on behalf of the Manufacturer should adopt an experimental approach to Verification Testing that would provide a broad market for their products, while recognizing the limitations of the equipment. The FTO should not adopt a verification experimental approach to removal of radionuclides that would be beyond the capabilities of the equipment. A wide range of contaminants or water quality problems that can be addressed by water treatment equipment varies, and some packaged treatment equipment can address a broader range of problems than other types. Manufacturers shall use NSF Equipment Verification Testing Plans as the basis for the development of the experimental plan in each specific FOD.

4.3.1 Feed Water Quality

One of the key aspects related to demonstration of equipment performance in the Verification Testing is the range of feedwater quality that can be treated successfully. The Manufacturer and FTO should consider the influence of feedwater quality on the quality of treated waters produced by the packaged plant, such that product waters meet the designated water quality goals stated in the FOD and were applicable, as driven by water quality goals, National Primary Drinking Water Standards and the EPA National Secondary Drinking Water Regulations. As the range of feed water quality that can be treated by the equipment becomes broader, the potential applications for treatment equipment with verified performance capabilities might also increase.

The FTO shall provide a list of radionuclides in the FOD that may be pertinent in equipment performance for removal of radionuclides. This list may include (but should not be limited to) some

of the radionuclides evaluated for removal during the verification removal testing program: radium, radon, uranium and alpha and beta emitters.

One of the questions often asked by regulatory officials in approval of package water treatment equipment is: "Has the packaged plant been shown to work on the water where it is proposed to be used?" By covering a large range of water qualities the Verification Testing is more likely to provide an affirmative answer to that question.

4.3.2 Treated Water Quality

Removal of radionuclides shall be the primary goal of the package and/or modular water treatment systems included in this Equipment Verification Testing Program. If a FTO states that water treatment equipment can be used to treat water to meet specified regulatory requirements for removal of radionuclides, the Verification Testing must provide data that support such a Statement of Capabilities, as appropriate. Where desired by the Manufacturer, the Statement of Performance Capabilities provided by the FTO shall be related to percent removal capabilities or to the National Primary Drinking Water Standards and the EPA National Secondary Drinking Water Regulations.

The FTO on behalf of the Manufacturer shall be responsible for identification of the specific radionuclides that shall be monitored during the Equipment Verification Testing Program. A State-certified, third-party accredited or EPA-accredited laboratory shall perform water quality analysis for the specific constituents in water samples provided by the FTO. This issue shall be discussed further in Section 5.2.

In addition, the FTO may wish to make a statement about performance capabilities of the equipment for removal of other unregulated, or regulated contaminants under the National Primary and Secondary Drinking Water Standards that are not directly related to radionuclide removal. For example, some water treatment equipment can be used to meet aesthetic goals that are not included as National Drinking Water requirements under the SDWA. Removal goals for some of these parameters may also be presented in the FOD as additional Statements of Performance Capabilities.

4.4 Radioactive Chemical Contaminants Testing

Analysis for radionuclides must be procedures that are approved or proven techniques. Before any method is used it must have standards. Methods have to have been shown by at least 3 laboratories to achieve a standard degree of uncertainty in analysis. Methods for radionuclide analysis are outlined in Standard or EPA Methods and shall be employed in this Verification Testing Program evaluation of radionuclides. Should an approved method be non-existent for an individual radionuclide, then a proposed method may be allowed. The manufacturer would be required to document and submit details of analytical procedures used to measure the specific radionuclide.

Frequency of sampling and radionuclide analysis shall be specified by the individual test plans used for the Equipment Verification Testing Program and shall also be stipulated in the FOD.

4.5 Recording Data

For all radionuclide experiments targeted towards removal of radionuclides, water quality data on feedwater, finished water, and wastewater should be maintained at a minimum on the identified

radionuclides and other water quality parameters identified by the FTO. The specific water quality parameters to be monitored and with what frequency shall be stipulated in the test plan employed for development of the FOD prior to initiation of the Verification Testing Program. At a minimum, the following conditions shall also be maintained for each experiment:

- Water type (raw water, pretreated feed water, product water, waste/wastewater);
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.);
- Type of chemical addition, dose and chemical combination (where applicable);
- Rate of flow through system, volume waste production as percent finished water flow, cumulative flow through system in terms of bed volumes (where applicable);
- Transmembrane pressure, membrane flux and element recovery (for membrane processes where applicable);
- Chemical cleaning frequency or regeneration frequency (where applicable);
- Voltage requirements, current draw and power consumption at specific operating conditions.

4.6 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95% confidence levels shall be calculated as the counting error by the FTO for selected water quality parameters. The FTO shall ensure in the FOD that sufficient water quality data and operational data are collected to allow estimation of statistical uncertainty. The specific testing plans that may be employed with the Protocol stipulate only a minimum frequency for monitoring of radionuclides. The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein. The specific testing plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence level describes a population range in which any individual population measurement may exist with a specified percent confidence.

The results of radioactivity analysis generally are reported in terms of "activity" per unit volume or mass at 20°C. The recognized unit for activity is the Becquerel, mBq. One Becquerel is equal to one disintegration per second. Other commonly used units are the picocurie (pCi) = 2.2 disintegrations per minute (dpm). Specific formulas for the calculation of activity per volume or mass are presented in the individual methods and use the general formula:

$$C = \frac{R_{net}}{e * y * i * v * d * u}$$

where:

C = activity per unit volume, in units or activity/mass or volume

R_{net} = net counts per minute

e = counting efficiency, cpm/dpm

y = chemical yield

i = ingrowth correction factor

v = volume or mass or portion

d = decay factor and

u -= units corrections factor

Radionuclide data are considered incomplete without reporting associated random a systematic errors. The following formula exemplifies calculation of the counting uncertainty at the 95 percent confidence:

$$E = \frac{1.96\left(R_o/t_1 + B/t_2\right)^{1/2}}{e * y * i * v * d * u}$$

where:

E = counting error

R_o = gross sample cpm

t_1 = sample count duration, min

B = background cpm

t_2 = background duration, min

Calculation of confidence levels shall not be required for equipment performance results (e.g., flow rate, cleaning efficiency, etc.) obtained during the equipment Testing Verification Program. However, as specified by the FTO, calculation of confidence levels may be required for analytical parameters such as radionuclides. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period. The procedures and sampling requirements shall be provided in detail in the Verification Testing Plan.

4.7 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations are intended to be conducted so that equipment can be tested to be sure it is functioning as intended. If feed water (or source water) quality influences operation and performance of equipment being tested, the initial operations period serves as the "shake-down" period for determining appropriate operating parameters. The schedule of testing may also be influenced by coordination requirements with a utility.

For water treatment equipment involving removal of radionuclides, an initial period of bench-scale testing of feedwater followed by treatment equipment operation may be needed to determine the appropriate operational parameters for testing equipment. A number of operational parameters may require adjustment to achieve successful functioning of the process train. These parameters may include but are not limited to: hydraulic loading rates, process flow rates, feedwater pH, chemical dosages, chemical types (where appropriate) and other parameters that may result in successful functioning of the process train. Chemical type, chemical dosages, and other operations that result in successful functioning of the packaged process should be included.

It is recommended under this protocol that a minimum of one 60-day test period of Verification Testing be conducted in order to allow testing over a period of time to collect representative data. The specific

operating and water quality parameters shall be stipulated by the selected Test Plan under this protocol and shall be used in development of the experimental plan and the preparation of the FOD.

Content of FOD Regarding Experimental Design

The FOD shall include the following elements:

- *Identification of the qualitative and quantitative factors of equipment operation to be addressed in the Verification Testing Program.*
- *Identification and discussion of the particular water treatment issues and radionuclide concentrations that the equipment is designed to address, how the equipment will solve the problem, and who would be the potential users of the equipment.*
- *Identification of the range of key water quality parameters, given in applicable NSF Testing Plans, which the equipment is intended to address and for which the equipment is applicable.*
- *Identification of the key parameters of treated water quality and analytical methods that will be used for evaluation of equipment performance during the removal of radionuclides. Parameters of significance for treated water quality are listed in applicable NSF Testing Plans.*
- *Description of data recording protocol for equipment operation, feed water quality parameters, and treated water quality parameters.*
- *Description of the confidence interval calculation procedure for selected water quality parameters.*
- *Detailed outline of the Verification Testing schedule, with regard to annual testing periods that will cover an appropriate range of annual climatic conditions, (i.e., different temperature conditions, seasonal differences between rainy and dry conditions).*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The NSF Verification Testing Plan specifies procedures that shall be used to provide accurate documentation of both equipment performance and treated water quality. Careful adherence to these procedures will result in definition of verifiable performance of equipment. The specific reporting techniques, methods of statistical analysis and the QA/QC of reporting radionuclide removal data shall be stated explicitly by the FTO in the FOD before initiation of the Verification Testing Program. (Note that this protocol may be associated with a number of different NSF Equipment Verification Testing Plans for different types of process equipment capable of achieving removal of various radionuclides).

The design aspects of water treatment process equipment often provide a basis for approval by State regulatory officials and can be employed under higher or lower flow rate conditions. The field operations procedures and testing conditions provided by the FTO shall therefore be specified to demonstrate treatment capabilities over a broad range of operational conditions and feedwater qualities.

Initial operations of the radionuclide removal equipment will allow FTOs to refine the equipment operating procedures and to make operational adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the FOD, if necessary. A failure at this point in the Verification Testing could indicate a lack of capability of the process equipment and the Verification Testing might be cancelled. Specific design aspects to be included in the FOD are provided in detail, in the Manufacturer Responsibilities section below.

5.2 Selection of Analytical Laboratory and Field Testing Organization

To assess the performance of the equipment, the quality of the treated water produced using the equipment shall be determined by analysis at a State-certified, third-party accredited or EPA-accredited laboratory with proven experience in detection and measurement of radionuclides. In all cases, current EPA Standard Methods procedures shall be used in analysis of specified water quality parameters. The NSF may provide a list of qualified laboratories from which Manufacturers can select for submission of samples for water quality analysis. Because of the variability of acceptance of laboratories from State to State, use of analytical laboratories certified in a large number of States is recommended. Furthermore, the selected analytical laboratory must be certified by the State in which the Verification Testing is being performed. Analytical results from the laboratory are to be provided directly to the NSF to maintain data integrity.

For field testing operations, the Manufacturer shall employ a NSF-qualified FTO; the list of qualified organizations may include engineering consulting firms, universities, or other qualified scientific organizations with experience operating pilot plant equipment. If a particular radionuclide does not have an accepted standard method procedure, then an analytical testing plan shall be submitted to NSF describing the procedure.

5.3 Communications, Documentation, Logistics, and Equipment

NSF shall communicate regularly with the Verification Testing participants to coordinate all field activities associated with this Verification Testing and to resolve any logistical, technical, or QA/QC issues that may arise as the Verification Testing progresses. The successful implementation of the Verification Testing will require detailed coordination and constant communication between all Verification Testing participants.

All field activities shall be thoroughly documented. Field documentation will include:

- field logbooks;
- photographs;
- field data sheets; and
- chain-of-custody forms.

The qualified FTO shall be responsible for maintaining all field documentation. The field logbook shall have at least the following requirements.

- Field notes shall be kept in a bound logbook.
- Each page shall be sequentially numbered and labeled with the project name and number.

- Field logbooks shall be used to record all water treatment equipment operating data.
- Completed pages shall be signed and dated by the individual responsible for the entries.
- Errors shall have one line drawn through them and this line shall be initialed and dated.

All photographs shall be logged in the field logbook. These entries shall include the time, date, direction, and subject of the photograph, and the identity of the photographer. Deviations from the approved final FOD shall be thoroughly documented in the field logbook at the time of inspection and in the verification report.

Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided at the time of the QA/QC inspection and included in the verification report.

As available, electronic data storage and retrieval capabilities shall be employed in order to maximize data collection and minimize labor hours required for monitoring. The guidelines for use of data-loggers, lap-top computers, data acquisition systems etc., shall be detailed by the FTO in the FOD.

5.4 Initial Operations

Initial operations of the radionuclide removal equipment will allow the FTO to refine their operating procedures and to make operational adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the FOD, if necessary. A failure at this point in the Verification Testing could indicate a lack of capability of the process equipment and the Verification Testing might be canceled.

5.5 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform to requirements provided in the FOD that was developed and NSF-approved for the Verification Testing being conducted. All sampling and sample analysis conducted during the Verification Testing Program shall be performed according to the procedures detailed by the FTO in the FOD. As necessary for Verification analysis, state certified or EPA-qualified laboratories certified for analysis of inorganic constituents and other water quality parameters shall be selected to perform analytical services. A NSF-verified laboratory using an approved Standard Method may perform the analysis of radionuclides.

If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the situation must be discussed with the NSF technical lead. Any deviations from the approved final FOD shall be thoroughly documented.

During routine operation of water treatment equipment, the total number of hours during which the equipment is operated each day shall be documented. In addition, the number of hours each day during which the operator was working at the treatment plant performing tasks related to water treatment and the operation of the treatment equipment shall be documented. Furthermore, the qualified Testing Organization, the Water System or the Plant Operator shall describe the tasks performed during equipment operation.

Content of FOD Regarding Field Operations Procedures

The Manufacturer shall be responsible for:

- *Provision of all equipment needed for field work associated with this Verification Testing.*
- *Provision of a complete list of all equipment to be used in the Verification Testing. A table format is suggested.*
- *Provision of field operating procedures.*

The FTO shall be responsible for including the following elements in the FOD:

- *A table summary of the proposed time schedule for operating and testing.*
- *Field operating procedures for the equipment and performance testing, based upon the NSF Equipment Verification Testing Plan with listing of operating parameters, ranges for feedwater quality, and sampling and analysis strategy.*

6.0 QUALITY ASSURANCE PROJECT PLAN

The Quality Assurance Project Plan (QAPP) for this Verification Testing specifies procedures that shall be used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the Verification Testing will provide sound analytical results that can serve as the basis for performance verification.

6.1 Purpose and Scope

The purpose of this section is to outline steps that shall be taken by operators of the equipment and by the analytical laboratory to ensure that data resulting from this Verification Testing is of known quality and that a sufficient number of critical measurements are taken.

6.2 Quality Assurance Responsibilities

The FTO project manager is responsible for coordinating the preparation of the QAPP for this Verification Testing and for its approval by the NSF. The qualified testing organization project manager, with oversight from NSF, shall also ensure that the QAPP is implemented during all Verification Testing activities.

The Manufacturer and the NSF must approve the entire FOD including the QAPP before the Verification Testing can proceed. The NSF must review and either approve the QAPP or provide reasons for rejection of the QAPP. They should also provide suggestions on how to modify the QAPP to make it acceptable, provided that the Manufacturer has made a good faith effort to develop an acceptable QAPP (i.e. the QAPP is 75 to 80% acceptable with only minor changes needed to produce an acceptable plan. NSF will not write QAPPs for Manufacturers.).

A number of individuals may be responsible for monitoring equipment operating parameters and for sampling and analysis QA/QC throughout the Verification Testing. Primary responsibility for ensuring

that both equipment operation and sampling and analysis activities comply with the QA/QC requirements of the FOD shall rest with the FTO. QA/QC activities for the equipment shall include those activities recommended by the Manufacturer and those required by the NSF to assure the Verification Testing will provide data of the necessary quality.

QA/QC activities for the NSF-certified analytical laboratory that analyzes samples sent off-site shall be the responsibility of that analytical laboratory's supervisor. If problems arise or any data appear unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section. The QA/QC measurements made by the off-site analytical laboratory are dependent on the analytical methods being used.

6.3 Data Quality Indicators

The data obtained during the Verification Testing must be of sound quality for conclusions to be drawn on the equipment. For all measurement and monitoring activities conducted for equipment verification, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include five indicators of data quality:

- Accuracy;
- Precision;
- Completeness;
- Representativeness; and
- Statistical Uncertainty

Treatment results generated by the equipment and by the laboratory analyses must be verifiable for the purposes of this program to be fulfilled. High quality, well-documented analytical laboratory results are essential for meeting the purpose and objectives of this Verification Testing. Therefore, the following indicators of data quality shall be closely evaluated to determine the performance of the equipment when measured against data generated by the analytical laboratory.

6.3.1 Accuracy

For water quality analyses, accuracy refers to the difference between a sample result and the reference or true value for the sample. Loss of accuracy can be caused by such processes as:

- errors in standards preparation;
- equipment calibrations;
- loss of target analyte in the extraction process;
- interferences; and
- systematic or carryover contamination from one sample to the next.

In this Verification Testing, accuracy will be ensured by

- maintaining consistent sample collection procedures, including sample locations;
- timing of sample collection;

- sampling procedures;
- sample preservation;
- sample packaging;
- sample shipping; and
- by random spiking procedures for the specific inorganic constituents chosen for testing.

The FTO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological sampling and analytical techniques in the FOD.

For water quality analysis, accuracy is usually expressed as the percent recovery. Percent recovery is the amount recovered during analysis. In general percent recovery can be calculated by dividing the measured amount added to the amount actually added.

$$\% \text{ Recovery} = \frac{\text{Measured}_{\text{Sample + Spike}} - \text{Measured}_{\text{Sample}}}{\text{Actual}_{\text{Spike}}} * 100\% = \frac{\text{Measured}_{\text{Spike}}}{\text{Actual}_{\text{Spike}}} * 100\%$$

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For equipment operating data, accuracy entails collecting a sufficient quantity of data during operation to be able to detect a change in operations. For water flow, accuracy may be the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times (bucket and stopwatch technique) as practiced in hydraulics laboratories or water meter calibration shops. For mixing equipment, accuracy is the difference between an electronic readout for equipment rotations per minute (rpms) and the actual measurement based on counted revolutions and measured time. Accuracy of head loss measurement can be determined by using measuring tapes to check the calibration of piezometers for gravity filters or by checking the calibration of pressure gauges for pressure filters. Meters and gauges must be checked periodically for accuracy, and when proven to be dependable over time, the time interval between accuracy checks can be increased. In the FOD, the FTO shall discuss the applicable ways of determining the accuracy of the operational conditions and procedures.

6.3.2 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. Precision measures the repeatability of measurement. It is usually expressed as the percent relative standard deviation (% RSD). In general % RSD can be calculated by dividing the standard deviation by the average. The methods to be employed for use of deviation shall be described by the FTO in the FOD.

$$\% \text{ RSD} = \frac{\text{Standard Deviation}}{\text{Average}} * 100\% = \frac{\sqrt{\sum_{i=1}^{n} \frac{\left(y_i - \bar{y}\right)^2}{n-1}}}{\sum_{i=1}^{n} \frac{y_i}{n}} * 100\%$$

y_i = sample measurement

n = number of samples

6.3.3 Completeness

Completeness refers to the amount of data collected from a measurement process compared to the amount that was expected to be obtained. For this Verification Testing, completeness refers to the proportion of valid, acceptable data generated using each method. The completeness objective for data generated during this Verification Testing will be 85 percent, in that at a minimum this portion of the required data for the selected test plan will be reported at the conclusion of each testing period.

6.3.4 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this Verification Testing, representativeness will be ensured by maintaining consistent sample collection procedures, including:

- sample locations;
- timing of sample collection;
- sampling procedures;
- sample preservation;
- sample packaging;
- sample shipping;
- sample equipment decontamination; and
- blind spikes.

Using each method at its optimum capability to provide results that represent the most accurate and precise measurement that it is capable of achieving also will ensure representativeness. For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations.

6.3.5 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence level around the sample mean. Description of the confidence level calculation is provided in Section 4.6 – Recording Statistical Uncertainty.

6.4 Water Quality and Operational Control Checks

This section describes the QC requirements that apply to both the treatment equipment and the on-site measurement of water quality parameters. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

The quality control checks provide a means of measuring the quality of data produced. The Manufacturer may not need to use all of the checks identified in this section. The selection of the appropriate quality control checks depends on the:

- equipment;
- experimental design; and
- performance goals.

The selection of quality control checks will be based on discussions among the Manufacturer and the NSF. Some types of quality control checks applicable to operating water treatment equipment were described in Section 6.3.3.

6.4.1 Quality Control for Equipment Operation

This section will explain the methods to be used to check on the accuracy of equipment operating parameters and the frequency with which these quality control checks will be made. A key aspect of the Equipment Verification Testing Project is to provide operating results that will be widely accepted by State regulatory officials. If the quality of the equipment operating data can not be verified, then the water quality analytical results may be of no value. Because water can not be treated if equipment is not operating within specification, obtaining valid equipment operating data is a prime concern for Verification Testing.

An example of the need for QC for equipment operations is an incident of state rejection of test data because the treatment equipment had no flow meter to use for determining engineering and operating parameters related to flow.

6.4.2 Water Quality Data

After treatment equipment is operating within specifications and water is being treated, the results of the treatment are interpreted in terms of water quality. Therefore the quality of water sample analytical results is just as important as the quality of the equipment operating data. Therefore, the QAPP must emphasize the methods to be employed for sampling and analytical QA. The important aspects of sampling and analytical QA are given below:

6.4.2.1 Triplicate Analysis of Selected Water Quality Parameters

Triplicate samples shall be analyzed for selected water quality parameters at specified intervals in order to determine the precision of analysis. The procedure for determining samples to be analyzed in triplicate shall be provided in each Verification Testing Plan with the required frequency of analysis and the approximate number. The triplicate analysis shall be performed according to the requirements for calculation of 95% confidence intervals, as presented in Section 4.6.

6.4.2.2 Method Blanks

Method blanks are used for selected water quality parameters to evaluate analytical method-induced contamination, which may cause false positive results.

6.4.2.3 Spiked Samples

The use of spiked samples will depend on the testing program, and the contaminants to be removed. If spiked samples are to be used specify the procedure, frequency, acceptance criteria, and actions if criteria are not met.

6.4.2.4 Travel Blanks

Travel blanks for selected water quality parameters shall be provided to the analytical laboratory to evaluate travel-related contamination.

6.4.2.5 Performance Evaluation Samples for On-Site Water Quality Testing

Performance evaluation (PE) samples are samples whose composition is unknown to the analyst. These are also known as blind spikes. Analysis of PE samples shall be conducted for selected water quality parameters before pilot testing is initiated by submission of samples to the analytical laboratory and to the equipment testing organizations, if appropriate. Control limits for the PE samples will be used to evaluate the equipment testing organization's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies done under this protocol would be a turbidity PE sample.

PE samples come with statistics about each sample which have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include:

- a true value of the PE sample;
- a mean of the laboratory results obtained from the analysis of the PE sample; and
- an acceptance range for sample values.

The analytical laboratory is expected to provide results from the analysis of the PE samples that meet the performance objectives of the Verification Testing.

6.5 Data Reduction, Validation, and Reporting

To maintain good data quality, specific procedures shall be followed during data

- Reduction;
- Validation; and
- Reporting.

These procedures are detailed below.

6.5.1 Data Reduction

Data reduction refers to the process of converting the raw results from the equipment into concentration or other data in a form to be used in the comparison. The procedures to be used will be equipment dependent. The purpose of this step is to provide data, which will be used to verify the Statement of Performance Capabilities. These data shall be obtained from logbooks, instrument outputs, and computer outputs, as appropriate.

6.5.2 Data Validation

The operator shall verify the completeness of the appropriate data forms and the completeness and correctness of data acquisition and reduction. The field team supervisor or another technical person shall review calculations and inspect laboratory logbooks and data sheets to verify precision, accuracy and completeness. The individual operators and the laboratory supervisor will examine calibration and QC data. Laboratory and project managers shall verify that all instrument systems are in control and that QA objectives for precision, accuracy, completeness, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for precision and accuracy for a given analytical method. Should QC data be outside of control limits, the analytical laboratory or field team supervisor will investigate the cause of the problem. If the problem involves an analytical problem, the sample will be reanalyzed. If the problem can be attributed to the sample matrix, the result will be flagged with a data qualifier. This data qualifier will be included and explained in the final analytical report.

6.5.3 Data Reporting

The data reported during the Verification Testing Program shall be explicitly defined by the FTO in the FOD. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses, the results of radionuclide removal analyses and equipment operating data. All QC information such as calibrations, blanks and reference samples are to be included in an appendix. All raw analytical data shall also be reported in an appendix. All data shall be reported in hardcopy and electronically in a common spreadsheet or database format.

6.6 Calculation of Data Quality Indicators

The equations for any data quality indicator calculations employed shall be provided. These include: precision, standard deviation, confidence interval, accuracy, and completeness.

6.7 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories may be conducted as specified by the NSF Equipment Verification Testing Plan. These inspections will be performed by the verification entity to determine if the NSF Equipment Verification Testing Plan is being implemented as intended. At a minimum, NSF shall conduct one audit of the sampling activities, field operations program and laboratories during Verification Testing. The number of audits performed during a study shall be specified by the pertinent Equipment Verification Testing Plan. Separate inspection reports will be completed after the audits and provided to the participating parties.

6.8 Reports

6.8.1 Status Reports

The FTO shall prepare periodic reports for distribution to pertinent parties, e.g., manufacturer, EPA, the community. These reports shall discuss:

- project progress;
- problems and associated corrective actions; and
- future scheduled activities associated with the verification testing.

Each report shall include an executive summary at the beginning of the report to introduce the salient issues of the testing period. When problems occur, the Manufacturer and FTO project managers shall discuss them, and estimate the type and degree of impact, and describe the corrective actions taken to mitigate the impact and to prevent a recurrence of the problems. The frequency, format, and content of these reports shall be outlined in the FOD.

6.8.2 Audit Reports

Any QA inspections that take place in the field or at the analytical laboratory while the Verification Testing is being conducted shall be formally reported by the:

- FTO;
- Verification entity; and
- Manufacturer.

6.9 Corrective Action

Each FOD must incorporate a corrective action plan. This plan must include the predetermined acceptance limits, the corrective action to be initiated whenever such acceptance criteria are not met, and the names of the individuals responsible for implementation.

Routine corrective action may result from common monitoring activities, such as:

- Performance evaluation audits
- Technical systems audits

Content of FOD Regarding Quality Assurance Project Plan

The FOD shall include the following elements:

- *Description of methodology for measurement of accuracy.*
- *Description of methodology for measurement of precision.*
- *Description of the methodology for use of blanks, the materials used, the frequency, the criteria for acceptable method blanks and the actions if criteria are not met.*
- *Description of any specific procedures appropriate to the analysis of the PE samples.*
- *Outline of the procedure for determining samples to be analyzed in triplicate, the frequency and approximate number.*
- *Description of the procedures used to assure that the data are correct.*
- *Listing of techniques and/or equations used to quantify any necessary data quality indicator calculations in the analysis of water quality parameters. These include: accuracy, precision, completeness (e.g., standard deviation, and confidence interval calculation).*
- *Outline of the frequency, format, and content of reports in the FOD.*
- *Development of a corrective action plan in the FOD.*

The FTO shall be responsible for proving and including the following elements in the FOD:

- *Provision of all QC information such as calibrations, blanks and reference samples in an appendix. All raw analytical data shall also be reported in an appendix.*
- *Provision of the inspection results in an appendix.*
- *Provision of all data in hardcopy and electronic form in a common spreadsheet or database format.*

7.0 DATA MANAGEMENT, ANALYSIS AND REPORTING

7.1 Data Management and Analysis

The responsibilities of the FTO for data management and analysis have been provided in the Responsibilities Summary Sheet, the Project Guidance Manual, and/or the Terms and Conditions cited earlier in this protocol. The Manufacturer, qualified FTO and NSF each have distinct responsibilities for managing and analyzing Verification Testing data. The equipment FTO is responsible for managing all the data and information generated during the Verification Testing. The Manufacturer is responsible for

furnishing those records generated by the equipment FTO. NSF will be responsible for analysis and verification of the data.

A variety of data will be generated during a Verification Testing. Each piece of data or information identified for collection in the NSF Equipment Verification Testing Plan will need to be provided in the report. The data management section of the FOD shall describe what types of data and information needs to be collected and managed, and shall also describe how the data will be reported to the NSF for evaluation.

The raw data and the validated data must be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet, and a data dictionary shall be provided. In addition to the sample results, all QA/QC summary forms must be provided.

Other items that must be provided include:

- field notebooks;
- photographs, slides and videotapes (copies); and
- results from the use of other field analytical methods.

7.2 Report of Equipment Testing

The FTO shall prepare a draft report describing the Verification Testing that was carried out and the results of that testing. This report shall include the following topics:

- Introduction
- Executive Summary
- Description and Identification of Product Tested
- Procedures and Methods Used in Testing
- Results and Discussion
- Conclusions and Recommendations
- References
- Appendices
- Manufacturer FOD
- QA/QC Results
- Audit Report

The NSF will review the draft report, the results of testing, the audit report, the QA/QC results, and will issue a final report.

Content of FOD Regarding Data Management and Analysis, and Reporting

The FOD shall include the following:

- *Description of what types of data and information needs to be collected and managed.*
- *Description of how the data will be reported to the NSF for evaluation*.

8.0 SAFETY AND MAINTENANCE CONSIDERATIONS

The safety procedures shall address safety considerations and include adherence to all local, State and federal regulations relative to safety and operational hazards. The safety procedures shall address safety considerations, including the following as applicable:

- Storage, handling and disposal of hazardous chemicals including acids, caustic and oxidizing agents;
- Conformance with electrical codes;
- Chemical hazards and biohazards; and
- Ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard.

For additional information on pilot plant and laboratory safety see:

i. Palluzi, R. P. Pilot Plant and Laboratory Safety. New York: McGraw-Hill, 1994.

ii. Fuscaldo, A. A., et al. Laboratory Safety, Theory and Practice. New York: Academic Press. 1980.

Content of FOD Regarding Safety

The Manufacturer shall be responsible for:

- *Provisions of required written material (such as Material Data Safety Sheets).*
- *Compliance with all safety requirements of local, State and federal laws and regulators.*
- *Provisions of maintenance information and troubleshooting guidelines and instructions relative to the equipment to be verified.*

The FOD shall include the following:

- *Address safety considerations that are appropriate for the equipment being tested and for the chemicals employed in the Verification Testing.*

9.0 SUGGESTED READING

Atoulikian, Richard G. "Proper Design of Radon Removal Facilities for Cost-Effective Treatment." Journal NEWWA. December 1997.

Cothern, C. Richard, and Rebers, Paul A. Radon, Radium and Uranium in Drinking Water. Lewis Publishers, Chelsea, MI 1990.

Deininger, Rolf A. "Monitoring for Radon in Water." Journal AWWA.

Dixon, Kevin L., Lee, Ramon G., Smith, James and Zielinski, Paul "Evaluating Aeration Technology for Radon Removal." Journal AWWA - Research and Technology, April 1991.

Dixon, Kevin L. and Lee, Ramon G., "Occurrence of Radon in Well Supplies." Journal AWWA - Management and Operations, July 1988.

Dzombak, David A., Roy, Sujoy B. and Fang, Hung-Jung, "Air-Stripper Design and Costing Computer Program." Journal AWWA - Management and Operations, October 1993.

Freiburger, Eric J., Jacobs, Timothy L. and Ball, William P., "Probabilistic Evaluation of Packed-Tower Aeration Designs for VOC Removal." Journal AWWA - Research and Technology. October 1993.

Graves, Barbara, Radon in Ground Water, Lewis Publishers/NWWA Conference, Chelsea, MI 1987.

Hand, David W., Crittenden, John C., Gehin, Joseph L. and Lykins, Jr., Benjamin W., "Design and Evaluation of an Air-Stripping Tower for Removing VOCs from Groundwater." Journal AWWA - Research and Technology, September 1986.

Kinner, Nancy E., Malley, Jr., James P., Clement, Jonathan A. and Fox, Kim R., "Using POE Techniques to Remove Radon." Journal AWWA - Research and Technology, June 1993.

Lowry, Jerry D., "Measuring Low Radon Levels in Drinking Water Supplies." Journal AWWA - Research and Technology, April 1991

Martins, K.L., "Practical Guide to Determine the Impact of Radon and Other Radionuclides on Water Treatment Processes." Water Scientific Tech. 26:1255-1264, Great Britain 1992.

Parrotta, Marc J., "Radioactivity in Water Treatment Wastes: A USEPA Perspective." Journal AWWA - Management and Operations, April 1991.

Pontius, Frederick W. and Paris, David B., "Congress to Decide Fate of Radon Standard." Journal AWWA - Legislation/Regulation, January 1994.

Rand, Peter W., Lacombe, Eleanor H. and Perkins, Jr., W. Dana, "Radon in Homes Following Its Reduction in a Community Water Supply." Journal AWWA - Research and Technology, April 1991.

USEPA. Multimedia Risk and Cost Assessment of Radon. Report to the United States Congress on Radon in Drinking Water. EPA #811-R-94-001, March 1994.

CHAPTER 2

NSF EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF RADIOACTIVE CHEMICAL CONTAMINANTS BY CATION AND ANION EXCHANGE TECHNOLOGIES

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LIST OF ABBREVIATIONS

FOD	Field Operations Document
FTO	Field Testing Organization
gpm/sf	Gallons per minute per square foot
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
meq/mL	milli-equivalent per milliliter
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
NPDES	National Pollutant Discharge Elimination System
NSF	NSF International
O&M	operation and maintenance
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
rpm	revolutions per minute
% RSD	percent relative standard deviation
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WSWRD	Water Supply and Water Resources Division
WTP	water treatment plant

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Testing Verification Plan (Plan) for evaluation of for cation and anion exchange technologies to be used within the structure provided by NSF's "*Protocol for Equipment Verification Testing of the Removal of Radioactive Chemical Contaminants by Packaged and/or Modular Drinking Water Treatment Systems* . This Plan is to be used as a guide in the development of the Field Operations Document (FOD) for testing of ion-exchange process equipment to achieve removal of radionuclides.

In order to participate in the equipment verification process for ion-exchange processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of a FOD. The FTO shall clearly specify in its FOD the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The FOD should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the FOD should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of radionuclides present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Capabilities (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters, or alternatively established one based upon compliance with drinking water standards. For example, the Manufacturer could include in the FOD a Statement of Performance Capabilities that would achieve compliance with maximum contaminant levels (MCLs) stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for a specific water quality parameter. The experimental design of the FOD shall be developed to address the specific Statement of Performance Capabilities established by the Manufacturer. Each FOD shall include all of the included tasks, Tasks 1 to 8.

2.0 INTRODUCTION

Ion-exchange processes are currently in use for a number of water treatment applications ranging from removal of color, hardness, radionuclides and other constituents.

In order to establish appropriate operations, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the

Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Prefiltration processes ahead of ion-exchange systems are generally required to remove particulate material and to ensure provision of high quality water to the ion-exchange systems. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the ion-exchange process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of the ion-exchange process at all times during the Equipment Verification Testing Program.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Capabilities must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Capabilities that may be verified in this testing. Examples include two statements shown in Table 3.1:

For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided:

- percent removal of the targeted radionuclides;
- rate of treated water production;
- recovery;
- feedwater quality regarding pertinent water quality parameters;
- temperature;
- concentration of target radionuclide; and
- other pertinent water quality and operational conditions.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities.

Table 3.1: Example Statements of Performance Capabilities for Radionuclide Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Radionuclide Removal	This packaged plant is capable of achieving 90 percent removal of radium during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total hardness concentrations less than 200 mg/L as $CaCO_3$.
Regulatory Compliance	This packaged plant is capable of producing a product water meeting the National Primary Drinking Water Standards for radium concentration during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total hardness concentrations less than 200 mg/L as $CaCO_3$.

This NSF Equipment Verification Testing Plan is broken down into 8 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan.

4.0 BACKGROUND

This section provides an overview of the literature review related to radionuclide regulations, health effects, and contaminant removal by ion-exchange technologies, and ion-exchange technology design. These items will assist in the following:

- Identifying the various radionuclide contaminants;
- Identifying the radionuclides that can be removed by various ion-exchange technologies;
- Defining various ion-exchange technologies capable of removing radionuclides;
- Defining ion-exchange technologies; and
- Describing the mechanisms that will help in qualifying and quantifying the removal efficiency of the ion-exchange technology tested.

4.1 Regulatory Review and Health Effects

The passage of the Safe Drinking Water Act of 1974 (SDWA) required the establishment of recommended maximum contaminant levels (MCLs) for compounds that were deemed undesirable for consumption in public water supplies. Since that time there has been a growing awareness of the need for

the control and removal of chemical contaminants from potable drinking water supplies. The 1986 Safe Drinking Water Act (SDWA) Amendments authorized the National Primary Drinking Water Regulations and required that the USEPA set such regulations on 83 contaminants including radionuclides.

Currently, the only radionuclides that are regulated include radium-226, radium-228, and alpha and beta emitters. Other radionuclides that are being considered for regulation include radon and uranium. The equipment verification tests will evaluate various technologies for the removal of radionuclides. The radionuclides that will be considered during the evaluation process are listed in Table 4.1 with their current regulatory MCLs.

TABLE 4.1: Radionuclides and Current Regulations

Radionuclides	Current MCL
Radium-226 & 228 Combined	5 pCi/L
Alpha Emitters	15 pCi/L
Beta Emitters	4 mrem/year
Radon	withdrawn
Uranium	0.02 mg/L (proposed)

In July 1991 the USEPA proposed a new rule for radionuclides in drinking water supplies (Federal Register Citation 56 GR 33050, Phase III Rule). More than 600 public comments submitted on the proposed rule were evaluated by the USEPA. Although a court deadline of April 1993 existed for the issuance of the final rule, the USEPA has delayed this deadline due to resource constraints.

The Phase III Rule is proposed to include MCLs of 0.02 mg/L for uranium and the MCL for radon has been withdrawn at this time. The expected Phase III Rule MCL of 20 pCi/L for combined radium-226 and radium-228 has also been withdrawn maintaining the current combined radium MCL at 5 pCi/L. Radium will very likely be separated and the radium MCL's may be more stringent particularly addressing radium-224. In order to minimize risks to human health, the exposure levels to these compounds must be reduced to the lowest level that is both technologically and economically feasible.

The chronic health hazards associated with the presence of radionuclides in drinking water have become a major concern of United States governmental agencies in more recent times. Radium is considered a bone seeker as it accumulates in the same organs as calcium. The ingestion of radium may lead to the development of abnormalities, cancer, or death. The lungs, myeloid stem cells, and bones of humans are particularly sensitive to such exposure. Diseases that are associated with radon in drinking water include stomach cancer from ingestion of drinking water, and lung cancer from inhalation of radon decay products released during household use of water. Associations of radon with other forms of cancer are considered negligible. Uranium has been shown to be carcinogenic and toxic to kidneys.

4.2 Definitions and Removal Processes for Radionuclides

4.2.1 Radium

Radium (Ra) is a naturally occurring radioactive element. There are two radium isotopes that are commonly found in groundwater. These isotopes include Ra-226, an alpha emitter that is part of the Uranium decay series, and Ra-228, a beta emitter that is part of the Thorium decay series. Radium is an alkaline earth metal chemically similar to calcium, barium, and strontium. It has a low solubility and does not form any soluble complexes that enhance its dissolution into groundwater. The minute mass that is present can only be detected as activity. The current MCLs for the radium isotopes were discussed previously.

4.2.2 Radon

Radon (Rn) is a naturally occurring noble gas that is an alpha emitting radionuclide. Radon is a chemically inert decay product of the Uranium series and is the immediate decay product of Ra-226. Radon is a noble gas, very mobile, and has a short half-life of just less than four days. Radon is only found in groundwater sources of water supply since it originates in the ground and naturally degasses from surface waters. The activity of radon in water and air is generally higher than that of other radionuclides. Radon in the public water supply enters a customer's home through the distribution system and is released into the indoor air when the water is used for household purposes such as washing and cleaning. Radon is not removed using ion-exchange processes. As mentioned previously, there is currently no MCL for Radon.

4.2.3 Uranium

Uranium (U) is a naturally occurring radioactive element that is can be found in ground and surface water supplies. There are three common alpha emitting isotopes of Uranium that include U-235 in the Actinium decay series, and U-234 and U-238 in the Uranium decay series. Uranium is less active than radium, and is generally found in natural waters in a complex ionic form, that varies with pH. As mentioned previously, there is currently no MCL for Uranium.

4.2.4 Removal Processes

Water supply systems that use sources that contain radionuclide concentrations above future MCLs will need to implement treatment techniques to comply with future regulations. Treatment processes that are available for the removal of radionuclides include, but are not limited to, cation and anion exchange resins, zeolites, adsorptive media, reverse osmosis membranes, and air stripping.

This Plan discusses the use of ion-exchange technologies for the removal of radionuclides. Ion-exchange is a water treatment technique utilized for the removal of ionic contaminants from water. Since radon is an inert gas, ion-exchange processes will not remove it. Therefore, the following section discusses the removal of Ra-226, Ra-228, and Uranium using ion-exchange processes.

4.3 Radionuclide Removal by Ion-Exchange Technologies

Ion-exchange treatment methods involve the exchange of ions from the raw water with presaturant ions from an exchange material. There are cation and anion exchange technologies. They include the removal of positively charged ions by cation exchange and the removal of negatively charged ions by anion exchange. Both cation and anion exchange treat raw water with radionuclides by exchanging the radium cations or uranium anions with presaturant cations and anions in an exchange media, respectively. Cation exchange is also capable of removing major hardness causing cations (*e.g.*, calcium, magnesium, etc.). The merit of ion-exchange process is its reversible reaction. When ion-exchange capacity is depleted, using an excess of the presaturant ion regenerates the exhausted ion-exchange material.

4.3.1 Cation Exchange

Cation exchange systems are capable of removing radium from raw water supply sources. This is due to the fact that radium occurs in natural water as a cation. This process provides softening, as well as, removal of Ra-226 and Ra-228. Radium is a divalent cation similar to calcium or magnesium. The cation exchange occurs using a cation exchange resin with presaturant cations such as sodium or hydrogen. Water treatment by cation exchange occurs with a cycle of service, backwash, regeneration, and rinse. Raw water is passed through the ion-exchange bed, and hardness causing ions, including radium, are replaced with sodium or hydrogen ions from the resin.

Almost complete hardness and radium removal can be achieved. Pretreatment for iron, if present, may increase the effectiveness of the cation exchange process, as well as, minimize regeneration and backwashing.

When the resin becomes exhausted or the finished water quality is less than desired, the ion-exchange bed is regenerated. Before a regeneration cycle, the exhausted resin bed should be backwashed. The backwash cycle is an up-flow wash performed at a manufacturer specified rate to provide removal of the entrapped particles. The backwash should be able to accomplish to cause 40 to 75 percent expansion of the resin bed.

The regenerant is typically a concentrated salt solution or brine (*e.g.*, 6-10 percent NaCl solution). The volume of the regenerant solution is only a fraction of the total volume of the raw water processed, resulting in a concentrated waste stream. The manufacturer will specify the pounds of salt per cubic foot of resin. When the regeneration cycle has been completed, a rinse cycle is provided to remove excess brine before a service cycle starts.

Disposal of the waste regenerant brine and backwash water is necessary. Disposal of the waste brine is limited by the radium concentration. The permitting of a disposal process for the ion-exchange treatment units may be a difficult process.

4.3.2 Anion Exchange

Anion exchange system operations are very similar to cation exchange systems. Anion exchange systems are capable of removing uranium from raw water supply sources. This is due to the fact that most uranium occurs in natural water as an anion. The design of anion exchange process is greatly different from the cation exchange process because the removal capacity for uranium is far greater than radium or hardness although it uses the same type equipment, and the same process flow

scenario. Specific gravities of anion exchange resins are lower than that of cation exchange resins. Therefore, the backwashing practice for anion exchange process needs to adopt a lower rate than cation exchange process.

Anion exchange does not provide hardness removal such as cation exchange. It does remove alkalinity (HCO_3^-) (low initial pH), sulfate, nitrate and arsenic during the first part of the cycle when operated to remove uranium. Since uranium is the most preferred of all anions, as time goes on uranium will "push" these other anions from the bed causing spikes and potential problems with sulfate, nitrate and arsenic. The pH will be depressed as a result. This should be considered in the testing of any anion exchange process.

4.4 Ion-Exchange Technology Design Considerations

The design capacity of an ion-exchange unit and associated resin can be determined based on the total amount of presaturant ions (counter ions) capable of exchange. The effective capacity is the percentage of the total capacity that may be utilized based on empty bed contact time, regeneration level, and regenerant flow rate. The capacity of an ion-exchange bed prior to exhaustion can be defined as the maximum number of equivalent ions that can be removed from solution per volume of resin.

Ion-exchange design considerations include, but are not limited to:

- Well pump capacity (gpm)
- Volumetric flow rate (gpm/cf or bed volumes per hour(BV/hr)
- Surface loading rates (gpm/sf)
- Hardness
- Prefilters
- Ion-Exchange Vessels
- Resin type
- Regenerant wastewater tank capacity
- Water temperature
- Empty bed contact time
- Water quality

Ion-exchange treatment units generally consist of vessels which contain the ion-exchange resin, a storage tank for regenerant salt, and a vessel for mixing of the brine solutions or brine eductor, and associated valves, pumps, piping, and controls. The ion-exchange tank or vessel may be pressurized or an open system type. Pretreatment is not normal for water supplies containing uranium and/or radium. Pretreatment with prefilters may be provided using spiral-wound cartridge filters. The diameter of the ion-exchange pressure vessel is typically limited to 12 feet in diameter.

The size of commercially available cation and anion exchange resins are generally in the range of 16 to 50 screen mesh size (US standard sieve). A variety of resins are available from various manufacturers. Flow rates are defined as volumetric flow rate (BV/hr) and surface area loading rate (gpm/sf). The volumetric flow rate is inversely related to the contact time of the solution and the resin. The surface loading rate is

a measure of the raw water flow rate through the resin bed. Blending is rarely used or permitted by regulatory agencies at the State level. When blending is utilized, only a fraction of the raw water is treated with the ion-exchange material. It is important that the ion-exchange bed and the blending ratios are designed to provide adequate removal of radionuclides to meet regulatory limits.

4.5 Waste Disposal

Waste disposal options include hauling and discharge into a wastewater treatment facility, injection into a disposal well or transportation to a facility. State and local regulatory agencies should be contacted to establish guidelines for treatment and disposal of wastes generated by ion-exchange processes. The regenerant waste stream from the ion-exchange regeneration process must be treated and/or disposed of in some manner. Effective regenerant disposal methods depend on the spent regenerant water quality, local regulations and site specific factors (AWWARF 1993). The handling and disposal of the wastes generated by treatment technologies removing naturally occurring radionuclides from drinking water pose concerns to the water supplier, to local and State governments and to the public at large. The potential handling hazards associated with radionuclides warrant the development of a viable ion-exchange regenerate disposal method. Information regarding concentrate disposal options can be found in Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides (USEPA, 1990). The document first addresses the management of radionuclide wastes by first describing the potential sources of these wastes (i.e., water treatment processes). Then there is a brief review of the known information on the radionuclide composition of the associated treatment wastes. The document then describes the plausible disposal alternatives and provides background information from related programs that should assist facilities in selecting a responsible option. The following are disposal options that must be approved by the State or local government prior to implementation of a waste disposal program.

Liquid Waste Disposal

- Direct discharge into storm sewers or surface water.
- Discharge into sanitary sewer.
- Deep well injection.
- Drying or chemical precipitation.

Solid Waste Disposal

- Temporary lagooning (surface impoundment).
- Disposal in landfill.
    a) Disposal without prior treatment.
    b) With prior temporary lagooning.
    c) With prior mechanical dewatering.
- Application to land (soil spreading/conditioning).
- Disposal at State licensed low-level radioactive waste facility.

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

- **Anion/Cation Exchange** Water treatment process where water is passed through a filter bed of exchange material. Anions/cations in the insoluble exchange material are displaced by ions from the raw water feed. The exchange material is used until the material is exhausted. The exchange material resin is regenerated with a solution such as sodium chloride.

- **Field Operations Document (FOD)** - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the USEPA/NSF Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

- **Field Testing Organization (FTO)** - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the FTO is to complete the application on behalf of the Manufacturer; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of a package plant during the intense periods of testing during the study and the tasks required by the Protocol.

- **Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

- **Raw** - Input stream to the ion-exchange process prior to any pretreatment.

- **Verification Statement** - A written document that summarizes a final report reviewed and approved by NSF on behalf of the USEPA or directly by the USEPA.

- **Water System** - The water system that operates using packaged water treatment equipment to provide potable water to its customers.

6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of package water treatment equipment utilizing ion-exchange technologies that include cation and anion exchange. Testing of ion-exchange equipment will be conducted by a NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a state certified or EPA qualified analytical laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and FOD for removal of radionuclides.

- **Task 1: Characterization of Raw Water** – Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.

- **Task 2: Equipment Verification Testing Plan** – Operate ion-exchange and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.
- **Task 3: Operations and Maintenance (O&M)** - Develop an O&M manual for each system submitted. The O&M manual shall characterize ion-exchange process design, outline an ion-exchange regeneration procedure or procedures, and provide an ion-exchange regenerant disposal plan.
- **Task 4: Data Collection and Management** Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 5: Radionuclide Removal -** Evaluate ion-exchange technology operations in relation to verified raw water quality.
- **Task 6: Finished Water Quality** – Evaluate the water quality produced by the ion-exchange technology as it relates to raw water quality and operational conditions.
- **Task 7: Quality Assurance / Quality Control (QA/QC)** – Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during ion-exchange equipment Verification Testing.
- **Task 8: Cost Evaluation** - Develop O&M costs for the submitted ion-exchange technology and package plant.

7.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 8) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the FOD, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the FOD that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the "*Protocol for Equipment Verification Testing of for Removal of Radioactive Chemical Contaminants*". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For ion-exchange process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants;
- Cold water, encountered in winter or at high altitude locations;
- High concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;

- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing program. Ion-exchange testing conducted beyond the required 60-day testing may be used for fine-tuning of ion-exchange performance or for evaluation of additional operational conditions. During the testing periods, evaluation of regeneration efficiency and finished water quality can be performed concurrent with ion-exchange operation testing procedures.

8.0 TASK 1: CHARACTERIZATION OF RAW WATER

8.1 Introduction

A characterization of raw water quality is needed to determine if the concentrations of Ra-226, Ra-228, and Uranium, or other raw water contaminants are appropriate for the use of ion-exchange processes. The feedwater quality can influence the performance of the equipment as well as the acceptance of testing results by Federal and State regulatory agencies.

8.2 Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of radionuclides;
- develop maximum and minimum concentrations for the contaminant; and
- develop a probable percentage of removal necessary to meet the proposed MCL.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

8.3 Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geological Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on ion-exchange process that is being tested. The following characteristics should be reviewed and documented:

- Radium-226
- Radium-228
- Uranium
- Total Alkalinity
- Turbidity
- Total Organic Carbon
- Fluoride
- Iron
- Manganese

- Temperature
- pH
- TDS
- Total Hardness
- Calcium Hardness
- True Color
- Chloride
- Sulfate
- Hydrogen Sulfide
- Nitrate
- Sodium
- Phosphate
- Arsenic

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized, the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

8.4 Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility or historical data. The historical water quality data can be used to determine the suitability of ion-exchange processes for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the Verification Testing of the ion-exchange equipment.

8.5 Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Capabilities for the removal of radionuclides. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For ion-exchange processes, a complete scan of water quality parameters may be required in order to determine pretreatment criteria.

9.0 TASK 2: EQUIPMENT VERFICATION TEST PLAN

9.1 Introduction

The equipment verification for ion-exchange technologies for radionuclide removal shall be conducted by a NSF-qualified, Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this NSF Plan shall be contracted with a State, NSF or EPA qualified laboratory. For information on a listing of NSF-qualified FTOs, contact NSF.

9.2 Objectives

The objective of this task is to operate the equipment provided by a Manufacturer, for the conditions and time periods specified by NSF and the Manufacturer.

9.3 Work Plan

9.3.1 Equipment Verification Test Plan

Table 9.1 presents the Tasks that are included in this Plan and will be included in the FOD for radionuclide removal by ion-exchange technologies. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing.

In the design of the FOD, the FTO shall stipulate which pretreatments are appropriate for application before the selected ion-exchange processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 9.1: Task Descriptions

No.	Task	Description
1	Characterization of Raw Water	Obtain chemical, microbiological and physical characterization of the raw water.
2	Test Plan	Water treatment equipment shall be operated for a minimum of four quarterly testing periods at a minimum of 30 days per test period to collect data on water quality and equipment performance.
3	O&M	Evaluate O&M manual for process.
4	Data Management	Develop data protocol between FTO and NSF.
5	Contaminant Removal	Evaluate radionuclide removal at selected set of operational conditions.
6	Finished Water Quality	Evaluate water quality at selected set of operational conditions.
7	QA/QC	Enforce QA/QC standards.
8	Cost Evaluation	Provide O&M costs of system.

9.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the package water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. In addition, the equipment should not be used for potable water production should a finished water quality parameter not comply with the requirements of the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

9.4 Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for ion-exchange technology performance.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. Ion-exchange technology testing conducted beyond the required 60-day testing may be used for fine-tuning of ion-exchange performance or for evaluation of additional operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

9.5 Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days. If package water treatment equipment is also operated for potable water production, the data supplied to the FTO shall be evaluated with regard to compliance with National Primary Drinking Water Standards or EPA National Secondary Drinking Water Regulations.

10.0 TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for ion-exchange technologies to be tested for radionuclide removal shall be included in the Verification Testing evaluation.

10.1 Objectives

The objective of this task is to provide an O&M manual that will assist in operating, troubleshooting and maintaining ion-exchange process performance. The O&M manual shall:

- characterize ion-exchange process design;
- outline an ion-exchange resin regeneration procedure or procedures; and
- provide a waste disposal plan.

The waste disposal plan must be approved by the State in question for permanent installation. A fully developed waste disposal plan is required because of the radionuclides that have been concentrated in the

waste stream. Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

Each specific test plan will include a list of criteria for evaluating O&M information. This shall be compiled and submitted for evaluation by USEPA, NSF and technical peer reviewers. An example is provided in Table 10.2. The purpose of this O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2 O&M Work Plan

Descriptions of ion-exchange technology unit process design shall be developed for the removal of radionuclides. Ion-exchange technologies shall include the design criteria and equipment characteristics. Examples of information required relative to the ion-exchange design criteria and characteristics are presented in Tables 10.3 and 10.4, respectively.

Depending on the raw water quality, periodic regeneration of the ion-exchange resin will be required. Regeneration of resin will be performed as necessary per manufacturer specifications. Resin may also require periodic replacement. Resin regeneration and material replacement should be noted so that it may be considered for the verification of the equipment.

TABLE 10.1: NSF Operations & Maintenance Manual Criteria - Ion-Exchange Package Plants

MAINTENANCE:

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- flow meters
- pressure gauges
- pumps
- motors
- valves
- chemical feeders
- ion-exchange vessel

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- resin
- piping

OPERATION:

The manufacturer should provide readily understood recommendation for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

Chemical feeders (if applicable):

- calibration check
- settings and adjustments - how they should be made
- dilution of chemicals - proper procedures

Monitoring and observing operation:

- removal calculations
- pressure readings/monitoring

TABLE 10.2: NSF Operations & Maintenance Manual Criteria - Ion-Exchange Package Plants (continued)

OPERATION (continued):

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water flow to plant;
- when the water flow rate through the package plant can not be controlled;
- no chemical feed;
- automatic operation (if provided) not functioning;
- no electric power; and

The following are recommendations regarding operability aspects of package plant ion-exchange technology processes. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program. During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects.

- are chemical feed pumps calibrated?
- are flow meters present and have they been calibrated?
- are pressure gauges calibrated?
- are pH meters calibrated?
- can regeneration be done automatically?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Cation and Anion Exchange Test Plan.

TABLE 10.3: Requirements for Maintenance and Operability of Ion-Exchange Package Plants

MAINTENANCE INFORMATION		
Equipment	**Maintenance Frequency**	**Replacement Frequency**
Pumps		
Valves		
Motors		
Chemical mixers		
Water meters		
Pressure gauges		
Piping		

MAINTENANCE INFORMATION: (rank from 1 (easiest) to 3 (most difficult), or N/A)	
Operation Aspect	**Response**
Chemical feed pumps calibration	
Flow meters calibration	
Pressure gauges calibration	
pH meters calibration	
TDS or conductivity meters calibration	
Regeneration	

Notes:

TABLE 10.4: Ion-Exchange Technology Design Criteria Reporting Items

Parameter	Unit
Type of unit	
Number of units	
Average flow rate (gpm)	
Maximum flow rate to unit (gpm)	
Minimum flow rate to unit (gpm)	
Resin type	
Resin volume (cf)	
Surface area at the resin/water interface (sf)	
Water temperature (^{o}C)	
Raw water Ra-226 concentration (pCi/L)	
Raw water Ra-228 concentration (pCi/L)	
Raw water Uranium concentration (pCi/L)	
Percent removal of Ra-226 (%)	
Percent removal of Ra-228 (%)	
Percent removal of Uranium (%)	
Pressure loss through system (psi)	
Service run time (hr)	
Empty bed contact time (min)	

TABLE 10.5: Ion-Exchange Equipment Characteristics

Parameter	Unit
Technology Manufacturer	
Equipment model number	
Resin type	
Filter area (sf)	
Design hydraulic loading rate (gpm/sf)	
Design pressure (psi)	
Standard testing removal (%)	
Standard testing pH	
Standard testing temperature (°C)	
Design concurrent flow velocity (fps)	
Maximum flow rate to the unit (gpm)	
Minimum flow rate to the unit (gpm)	
Acceptable range of operating pressures	
Acceptable range of operating pH values	
Typical pressure drop across a single unit (ft)	
Pumping requirements	
Suggested regeneration procedures	
Suggested resin replacement schedule	
Type of construction	
Estimated Purchase Price	
Other	

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each technology tested

11.0 TASK 4: DATA COLLECTION AND MANAGEMENT

11.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, and manual recording of operational parameters for the ion-exchange equipment on a daily basis.

11.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for the NSF for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3 Work Plan

11.3.1 Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of ion-exchange equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for three eight-hour shifts per day. (Daily measurements shall be recorded on data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet.) The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2 Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and

operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each ion-exchange technology test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state certified or EPA-qualified laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3 Statistical Analysis

For the analytical data obtained during Verification Testing, 95% confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0 TASK 5: RADIONUCLIDE REMOVAL

12.1 Introduction

The removal of Ra-226, Ra-228, and Uranium from drinking water supplies is accomplished by ion-exchange treatment. The effectiveness of ion-exchange processes for radionuclide removal will be evaluated in this task. Assessment of treatment technologies will be assessed based on percent removal of Ra-226, Ra-228, and Uranium.

12.2 Experimental Objectives

The objectives of this task are to demonstrate:

- Operational conditions for the ion-exchange equipment;
- Radionuclide removal achieved by the ion-exchange equipment; and
- Necessary regeneration and replacement of resin.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of ion-exchange operation at the operating conditions specified by the Manufacturer, as it pertains to percent removal of radionuclides.

12.3 Work Plan

Determination of ideal ion-exchange operating conditions for a particular water may require as long as one year of operation. The cycle period for uranium could easily be greater than the one-year period allocated and the virgin run is much better than subsequent runs. The superior performance in the virgin run is also true for radium removal by cation exchange, but there will ample time for many cycles during the one-year test period. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the ion-exchange system. The set of operating conditions shall be maintained for the 60-day testing period (24-hour continuous operation). The Manufacturer shall specify the primary hydraulic loading rate at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and "shakedown" of the ion-exchange equipment, ion-exchange operation should be established at the loading rate to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate ion-exchange performance under different raw water quality conditions. At a minimum the performance of the ion-exchange equipment relative to radionuclide removal shall be documented during those periods of variable raw water conditions. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions.

12.4 Ion-Exchange Removal Efficiencies

12.4.1 Operational Data Collection

Removal efficiencies of radionuclides from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and pressure and finished water flow and pressure shall be collected at a minimum of 3 eight-hour shifts per day. Table 12.1 is an example of a daily operational data sheet for an ion-exchange system. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific.

Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 12.2, except for radionuclides, which will be monitored prior to start-up and then weekly. Power costs for operation of the ion-exchange equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

12.4.2 Feedwater Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of ion-exchange performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished Ra-226, Ra-228, and Uranium concentrations over time for each 60-day test period.
- Plot graph of removal of Ra-226, Ra-228, and Uranium over time for each 60-day test period.

TABLE 12.1: Daily Operations Log Sheet for an Ion-Exchange Package Plant

Date:

Parameter	Shift 1	Shift 2	Shift 3
Time			
Initial			
Raw Water			
Q_{raw} (gpm)			
$Ra\text{-}226_{raw}$ (before pretreatment) (pCi/L)			
$Ra\text{-}226_{raw}$ (after pretreatment) (pCi/L)			
$Ra\text{-}228_{raw}$ (before pretreatment) (pCi/L)			
$Ra\text{-}228_{raw}$ (after pretreatment) (pCi/L)			
$Uranium_{raw}$ (before pretreatment) (pCi/L)			
$Uranium_{raw}$ (after pretreatment) (pCi/L)			
P_{raw} (psi)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Ion-exchange Vessel			
Q (gpm)			
Ra-226 (pCi/L)			
Ra-228 (pCi/L)			
Uranium (pCi/L)			
P (psi)			
Finished			
Q_{fin} (gpm)			
$Ra\text{-}226_{fin}$ (pCi/L)			
$Ra\text{-}228_{fin}$ (pCi/L)			
$Uranium_{fin}$ (pCi/L)			
Regeneration (@ what % brine or NaCl)			
Q_{regen} (gpm)			

TABLE 12.2: Operating and Water Quality Data Requirements for Ion-Exchange Processes

Parameter	Sampling Frequency
Raw Water Flow	3 * Daily
Finished Water Flow	3 * Daily
Regenerant Flow	3 * Daily
Raw Water Pressure	3 * Daily
Finished Water Pressure	3 * Daily
Regenerant Pressure	3 * Daily
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Costs (Kwh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Independent check on pressure gages	Weekly
Verification of chemical dosages	Monthly
Feed Water and Finished Water Characteristics	
Radium-226	Weekly
Radium-228	Weekly
Uranium	Weekly
Gross Alpha and Beta Emitters	Weekly
Temperature	3 * Daily
pH	3 * Daily
TDS/Conductivity	3 * Daily
Turbidity	Every two weeks
True Color	Every two weeks
Total Organic Carbon	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
Sodium	Every two weeks
Chloride	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Sulfate	Every two weeks
Fluoride	Every two weeks
Nitrate	Every two weeks
Hydrogen Sulfide	Every two weeks
Arsenic	Every two weeks

13.0 TASK 6: FINISHED WATER QUALITY

13.1 Introduction

Water quality data shall be collected for the raw and finished water as provided previously in Table 12.2. At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the ion-exchange equipment should be proven and reported in the FOD.

13.2 Objectives

The objective of this task is to verify the Manufacturer claims. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing has been provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the FOD.

13.3 Work Plan

The FOD shall identify the treated water quality objectives to be achieved in the Statement of Performance Capabilities of the equipment to be evaluated in the Verification Testing Program. The FOD shall also identify in the Statement of Performance Capabilities the radionuclide removal that shall be monitored during equipment testing. The Statement of Performance Capabilities prepared by the FOD shall indicate the range of water quality under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the Ion-Exchange Process Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Ion-Exchange Process Plan is oriented towards removal of Ra-226, Ra-228, and Uranium, the Manufacturer may want to look at the treatment systems removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A State, NSF or EPA qualified analytical laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 13.1. Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state certified or EPA-qualified laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radium-226	7500-Ra	903.1
Radium-228	7500-Ra	---
Uranium	7500-U	908.0
Gross Alpha and Beta Emitters	7110	900.0
Temperature	2550	170.1
pH	4500-H^+	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
True Color	2120	110.2
Total Organic Carbon	5310	415.2
UV Absorbance (254 nm)	5910	---
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Sodium	3500-Na	273.1
Chloride	4500-Cl^-	325.1
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Sulfate	4500-SO_4^{-2}	375.4
Fluoride	4500-F^-	340.1
Nitrate	4500-NO_3^-	352.1
Hydrogen Sulfide	4500-S^{-2}	---
Arsenic	3114	206.3

1) AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

2) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

13.4 Analytical Schedule

13.4.1 Removal of Radioactive Chemical Contaminants

During the steady-state operation of each ion-exchange testing period, radionuclide mass balances shall be performed on the raw water, resin, and finished water in order to determine the radionuclide removal capabilities of the ion-exchange system.

13.4.2 Raw Water Characterization

At the beginning of each ion-exchange testing period, the raw water and water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 12.2.

13.4.3 Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of ion-exchange equipment testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radionuclides and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

13.4.4 Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.2 is critical for the Verification Testing Program, as these parameters can substantially influence ion-exchange performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radionuclides.
- Water quality and removal goals specified by the Manufacturer.

14.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the ion-exchange process equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quality data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

14.3.1 Daily QA/QC Verification

- On-line pH meters (check and verify components)
- On-line conductivity meter (check and verify components)

14.3.2 Monthly QA/QC Verification

- Chemical feed pump flow rates (verify volumetrically over a specific time period) if used (Note: ion-exchange process does not use chemicals other than salt in most cases, unless pH adjustment is deemed necessary or acid/base regenerants are used)
- On-line flow meters/rotometers (clean equipment to remove any debris or microbiological buildup and verify flow volumetrically to avoid erroneous readings)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter).
- Piping (verify good condition of all piping and connections, replace if necessary)

14.4 Analytical Methods

Use of either bench-top field analytical equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by

inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 13.1 lists AWWA and EPA standard methods of analysis.

15.0 TASK 8: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of ion-exchange processes over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. The equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. Design parameters are summarized in Table 15.1. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons if pilot scale units are provided for Verification Testing purposes.

Operation and maintenance (O & M) costs realized in the equipment Verification Test can be utilized for cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical Dosage; and
- Equipment Replacement Frequency.

The O & M costs will vary based on geographic location.

O & M costs should be provided for each ion-exchange process that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 15.2.

Table 15.1: Design Parameters for Cost Analysis

Design Parameter	Specific Utility Values
Total required plant production (mgd)	
By-pass flow rate (mgd)	
Resin Type	
Resin Volume (cf)	
Surface loading rate (gpd/sf)	
Empty bed contact time (min)	

Table 15.2: Operations and Maintenance Cost

Cost Parameter	Specific Values
Labor rate + fringe ($/personnel-hour)	
Labor overhead factor (% of labor)	
Number of O&M personnel hours per week	
Electric rate ($/kWh)	
Resin replacement (# times/year)	
Chemical Dosage (per week)	

16.0 SUGGESTED READINGS

APHA, AWWA, and WEF. Standard Methods for the Examination of Water and Wastewater, 18th Edition, Washington D.C.

Atoulikian, Richard G. "Proper Design of Radon Removal Facilities for Cost-Effective Treatment." Journal NEWWA. December 1997.

AWWARF. Membrane Concentrate Disposal. Denver, CO, 1993.

Clifford, Dennis, et al. "Evaluating Various Adsorbents and Membranes for Removing Radium from Groundwater". Journal AWWA – Research and Technology, July 1988.

Cothern, C. Richard, and Rebers, Paul A. Radon, Radium and Uranium in Drinking Water. Lewis Publishers, Chelsea, MI 1990.

Deininger, Rolf A. "Monitoring for Radon in Water." Journal AWWA.

Dixon, Kevin L., Lee, Ramon G., Smith, James and Zielinski, Paul "Evaluating Aeration Technology for Radon Removal." Journal AWWA - Research and Technology, April 1991.

Dixon, Kevin L. and Lee, Ramon G., "Occurrence of Radon in Well Supplies." Journal AWWA - Management and Operations, July 1988.

Dzombak, David A., Roy, Sujoy B. and Fang, Hung-Jung, "Air-Stripper Design and Costing Computer Program." Journal AWWA - Management and Operations, October 1993.

Duranceau, S.J. "Membrane Process Post-Treatment." Supplement to AWWA Seminar Proceedings: Membrane Technology Conference. Baltimore, MD, 1993.

Graves, Barbara, Radon in Ground Water, Lewis Publishers/NWWA Conference, Chelsea, MI 1987.

Hand, David W., Crittenden, John C., Gehin, Joseph L. and Lykins, Jr., Benjamin W., "Design and Evaluation of an Air-Stripping Tower for Removing VOCs from Groundwater." Journal AWWA - Research and Technology, September 1986.

Jelinek, Robert T.; Sorg, Thomas J. "Operating a Small Full-Scale Ion-exchange System for Uranium Removal." Journal AWWA. July 1988.

Kinner, Nancy E., Malley, Jr., James P., Clement, Jonathan A. and Fox, Kim R., "Using POE Techniques to Remove Radon." Journal AWWA - Research and Technology, June 1993.

Lowry, Jerry D., "Measuring Low Radon Levels in Drinking Water Supplies." Journal AWWA - Research and Technology, April 1991

Lowry, Jerry D., Sylvia B. "Radionuclides in Drinking Water Supplies." Journal AWWA - Research and Technology, July, 1988.

Martins, K.L., "Practical Guide to Determine the Impact of Radon and Other Radionuclides on Water Treatment Processes." Water Scientific Tech. 26:1255-1264, Great Britain 1992.

McKelvey, Gregory A., et al. "Ion-exchange: A Cost-Effective Alternative for Reducing Radium". Journal AWWA. June 1993.

Parrotta, Marc J., "Radioactivity in Water Treatment Wastes: A USEPA Perspective." Journal AWWA - Management and Operations, April 1991.

Pontius, Frederick W. and Paris, David B., "Congress to Decide Fate of Radon Standard." Journal AWWA - Legislation/Regulation, January 1994.

Rand, Peter W., Lacombe, Eleanor H. and Perkins, Jr., W. Dana, "Radon in Homes Following Its Reduction in a Community Water Supply." Journal AWWA - Research and Technology, April 1991.

Sorg, T.J., et al.. "Removal of Radium-226 from Sarasota County Florida, Drinking Water by Reverse Osmosis". Journal AWWA - Research and Technology, April 1980.

Sorg, T.J., et al.. "Methods for Removing Uranium From Drinking Water". Journal AWWA, July 1988.

Subramonian, Suresh; et al. "Evaluating Ion-exchange for Removing Radium from Groundwater." Journal AWWA. May 1990.

Sung, L. K., Morris, K. E. and Taylor J. S. "Predicting Colloidal Fouling," International Desalination and Water Reuse Journal. November/December, 1994.

Takigawa, D. Y., Metcalfe, P. F., Chu, H. C., Light, W. G., Murrer, J. and Holden, P. "Ultra-Low Pressure Reverse Osmosis Membranes." Proceedings 1995 Membrane Technology Conference. Reno, NV, 1995.

Taylor, J.S., L.A. Mulford, S.J. Duranceau and W.M. Barret. "Cost and Performance of a Membrane Pilot Plant." JAWWA. November, 1989.

Taylor, J.S., S.J. Duranceau, W.M. Barrett, and J.F. Goigel. Assessment of Potable Water Membrane Applications and Research Needs. Denver: AWWA Research Foundation. 1990.

Taylor, J.S., J.A.M.H. Hofman, S.J. Duranceau, J.C. Kruithof and J.C. Schippers. "Simplified Modeling of Diffusion Controlled Membrane Systems." J. Water, SRJ-Aqua. May, 1994.

USEPA. Multimedia Risk and Cost Assessment of Radon. Report to the United States Congress on Radon in Drinking Water. USEPA #811-R-94-001, March 1994.

USEPA. Radionuclide Removal for Small Public Water Systems. Prepared for the Office of Drinking Water. USEPA #570-O-83-010, June 1983.

Weber, W.J. Physicochemical Processes for Water Quality Control. New York: John-Wiley & Sons. 1972.

Zhang, Zhihe; Clifford, Dennis A. "Exhausting and Regenerating Resin for Uranium Removal." Journal AWWA. April 1994.

CHAPTER 3

NSF EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF RADIOACTIVE CHEMICAL CONTAMINANT BY NANOFILTRATION MEMBRANE PROCESSES

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LIST OF ABBREVIATIONS

FOD	Field Operations Document
FTO	Field Testing Organization
HF	hollow fiber
HSD	homogeneous solution diffusion model
IMS	Integrated Membrane Systems
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MFI	modified fouling index
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
MTC	mass transfer coefficient
MWCO	molecular weight cut-off
NF	nanofiltration
NPDES	National Pollutant Discharge Elimination System
NSF	NSF International
O&M	operation and maintenance
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RO	reverse osmosis
rpm	revolutions per minute
% RSD	percent relative standard deviation
SCADA	Supervisory Control and Data Acquisition
SDI	silt density index
SDWA	Safe Drinking Water Act
TFC	thin-film composite
TOC	total organic carbon
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
USGS	United States Geographic Survey
WSWRD	Water Supply and Water Resources Division
WTP	water treatment plant

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Testing Verification Plan (Plan) for evaluation of nanofiltration (NF) membrane processes to be used within the structure provided by NSF's "*Protocol for Equipment Verification Testing of the Removal of Radioactive Chemical Contaminants by Packaged and/or Modular Drinking Water Treatment Systems* . This Plan is to be used as a guide in the development of the Field Operations Document (FOD) for testing of NF membrane processes to achieve removal of radionuclides. It should also be noted that this Equipment Verification Plan is only applicable to NF or other high-pressure membrane processes.

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of a FOD. The FTO shall clearly specify in its FOD the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The FOD should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the FOD should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of radionuclides present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Capabilities (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters, or alternatively established one based upon compliance with drinking water standards. For example, the Manufacturer could include in the FOD a Statement of Performance Capabilities that would achieve compliance with maximum contaminant levels (MCLs) stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for a specific water quality parameter. The experimental design of the FOD shall be developed to address the specific Statement of Performance Capabilities established by the Manufacturer. Each FOD shall include all of the included tasks, Tasks 1 to 9.

2.0 INTRODUCTION

Membrane processes are currently in use for a number of water treatment applications ranging from removal of inorganic constituents; total dissolved solids (TDS), total organic carbon (TOC), synthetic organic chemicals (SOCs), radionuclides and other constituents.

In order to establish appropriate operations conditions such as permeate flux, recovery, cross-flow velocity, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of

pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of RO systems are generally required to remove particulate material and to ensure provision of high quality water to the membrane systems. For example, RO membranes cannot generally be applied to treatment of surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the RO membrane process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of the membrane process at all times during the Equipment Verification Testing Program.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Capabilities must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Capabilities that may be verified in this testing. Examples include two statements shown in Table 3.1:

For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided:

- percent removal of the targeted radionuclides;
- rate of treated water production (i.e., flux);
- recovery;
- feedwater quality regarding pertinent water quality parameters;
- temperature;
- concentration of target radionuclide; and
- other pertinent water quality and operational conditions.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities.

Table 3.1: Example Statements of Performance Capabilities for Radionuclide Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Radionuclide Removal	This packaged plant is capable of achieving 90 percent removal of radium during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.
Regulatory Compliance	This packaged plant is capable of producing a product water meeting the National Primary Drinking Water Standards for radium concentration during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.

This NSF Equipment Verification Testing Plan is broken down into 9 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan. All permeate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 77 °F or liters per square meter per hour (L/(m^2-hr) at 25 °C.

4.0 BACKGROUND

This section provides an overview of the literature review related to radionuclide regulations, health effects, and contaminant removal by NF membrane processes. These items will assist in identifying the various radionuclide contaminants, identifying the radionuclides that can be removed by NF membrane processes, defining NF membrane processes and the mechanisms that will help in qualifying and quantifying the removal efficiency of the NF membrane processes tested.

4.1 Regulatory Review and Health Effects

The passage of the Safe Drinking Water Act of 1974 (SDWA) required the establishment of recommended maximum contaminant levels (MCLs) for compounds that were deemed undesirable for consumption in public water supplies. Since that time there has been a growing awareness of the need for the control and removal of chemical contaminants from potable drinking water supplies. The 1986 Safe Drinking Water Act (SDWA) Amendments authorized the National Primary Drinking Water Regulations and required that the USEPA set such regulations on 83 contaminants including radionuclides.

Currently, the only radionuclides that are regulated include radium-226, radium-228, and alpha and beta emitters. Other radionuclides that are being considered for regulation include radon and uranium. The equipment verification tests will evaluate various technologies for the removal of radionuclides. The radionuclides that will be considered during the evaluation process are listed in Table 4.1 with their current regulatory MCLs.\

TABLE 4.1: Radionuclides and Current Regulations

Radionuclides	Current MCL
Radium-226 & 228 Combined	5 pCi/L
Alpha Emitters	15 pCi/L
Beta Emitters	4 mrem/year
Radon	withdrawn
Uranium	0.02 mg/L (proposed)

In July 1991 the USEPA proposed a new rule for radionuclides in drinking water supplies (Federal Register Citation 56 GR 33050, Phase III Rule). More than 600 public comments submitted on the proposed rule were evaluated by the USEPA. Although a court deadline of April 1993 existed for the issuance of the final rule, the USEPA has delayed this deadline due to resource constraints.

The Phase III Rule is proposed to include MCLs of 0.02 mg/L for uranium while the MCL for radon has been withdrawn at this time. The expected Phase III Rule MCL of 20 pCi/L for combined radium-226 and radium-228 has also been withdrawn maintaining the current combined radium MCL at 5 pCi/L. Radium will very likely be separated and the radium MCL's may be more stringent particularly addressing radium-224. In order to minimize risks to human health, the exposure levels to these compounds must be reduced to the lowest level that is both technologically and economically feasible.

The chronic health hazards associated with the presence of radionuclides in drinking water have become a major concern of United States governmental agencies in more recent times. Radium is considered a bone seeker as it accumulates in the same organs as calcium. The ingestion of radium may lead to the development of abnormalities, cancer, or death. The lungs, myeloid stem cells, and bones of humans are particularly sensitive to such exposure. Diseases that maybe associated with radon in drinking water include stomach cancer from ingestion of drinking water, and lung cancer from inhalation of radon decay products released during household use of water. Associations of radon with other forms of cancer are considered negligible. Uranium has been shown to be carcinogenic and toxic to kidneys.

4.2 Definitions and Removal Processes for Radionuclides

4.2.1 Radium

Radium (Ra) is a naturally occurring radioactive element. There are two radium isotopes that are commonly found in groundwater. These isotopes include Ra-226, an alpha emitter that is part of the Uranium decay series, and Ra-228, a beta emitter that is part of the Thorium decay series. Radium is an alkaline earth metal chemically similar to calcium, barium, and strontium. It has a low solubility and does not form any soluble complexes that enhance its dissolution into groundwater. The minute mass that is present can only be detected as activity. The current MCLs for the radium isotopes were discussed previously.

4.2.2 Radon

Radon (Rn) is a naturally occurring noble gas that is an alpha emitting radionuclide. Radon is a chemically inert decay product of the Uranium series and is the immediate decay product of Ra-226. Radon is a noble gas, very mobile, and has a short half-life of just less than four days. Radon is only found in groundwater sources of water supply since it originates in the ground and naturally degasses from surface waters. The activity of radon in water and air is generally higher than that of other radionuclides. Radon in the public water supply enters a customer's home through the distribution system and is released into the indoor air when the water is used for household purposes such as washing and cleaning. As mentioned previously, there is currently no MCL for Radon.

4.2.3 Uranium

Uranium (U) is a naturally occurring radioactive element that can be found in ground and surface water supplies. There are three common alpha emitting isotopes of Uranium that include U-235 in the Actinium decay series, and U-234 and U-238 in the Uranium decay series. Uranium is less active than radium, and is generally found in natural waters in a complex ionic form, that varies with pH. As mentioned previously, there is currently no MCL for Uranium.

4.2.4 Removal Processes

Water supply systems that use sources that contain radionuclide concentrations above future MCLs will need to implement treatment techniques to comply with future regulations. Treatment processes that are available for the removal of radium and uranium include, but are not limited to, cation and anion exchange resins, zeolites, adsorptive media, reverse osmosis membranes, and lime softening. Radon can be removed using aeration technologies.

This Plan discusses the use of NF membrane processes for the removal of radionuclides. NF is a water treatment technique utilized for the removal of particulate contaminants from water. Since radon is a naturally occurring gas, NF membrane processes will not remove it. Therefore, the following section discusses the removal of Ra-226, Ra-228, and Uranium using NF membrane processes.

4.3 Radionuclide Removal by NF Membrane Processes

This NSF Equipment Verification Testing Plan is applicable to any NF membrane process used to achieve removal of radionuclides. Furthermore, this testing plan is applicable to spiral-wound (SW) and hollow-fiber (HF) membrane configurations.

Reverse osmosis (RO) has been shown to be highly effective for the removal of radionuclides such as radium and uranium. Radium and uranium removal has exceeded 87 and 98 percent, respectively, for diffusion controlled membranes. However, removal is a function of membrane mass transfer coefficients (MTCs), flux, recovery and feed concentration and will be expected to vary by membrane type. RO is also effective in producing a better overall quality of water.

Some advantages to the use of membrane processes for the removal of radionuclides include:

- a small space requirement;
- removal of contaminant ions, dissolved solids, bacteria, and particles; and
- relative insensitivity to flow and TDS levels, and low effluent concentration.

Disadvantages include:

- higher capital and operating costs;
- higher level of pretreatment required;
- possible membrane fouling; and
- large reject streams.

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications including the removal of radionuclides (e.g. Ra-226, Ra-228, and Uranium), natural organic matter (NOM) which contributes to disinfection by-product formation, dissolved minerals, synthetic organic compounds (SOCs) and microbial contaminants such as *Giardia* and *Cryptosporidium*. Typically, high-pressure membrane applications such as NF membrane processes are capable of removing radionuclides, as well as, ions contributing to hardness. Both radium and uranium are large molecules that have removal rates similar to those of calcium.

In contrast, membrane processes such as microfiltration (MF) and ultrafiltration (UF) are typically employed to provide a physical barrier for removal of microbial, particulate and suspended contaminants from drinking waters. However, the MF and UF membrane processes have not been shown to be effective for removal of radionuclides and other dissolved substances unless another unit operator such as granular activated or powdered activated carbon is employed.

High and low pressure diffusion controlled membranes are both effective for the rejection of radionuclides. Since NF (low pressure RO) is as effective as RO, and can pass more water at lower pressure operations than reverse osmosis, this test plan pertains to the removal of radium and uranium by NF membrane processes. Suppliers of drinking water are subject to stringent government regulations for potable water quality regarding allowable radionuclide (e.g. Ra-226, Ra-228, and Uranium) concentrations.

4.4 Membrane System Design Considerations

Conventional NF membrane systems consist of pretreatment, membrane processing and post-treatment. These processes are discussed in the following sections.

4.4.1 Pretreatment

The purpose of pretreatment is to control membrane fouling and reduce flux decline. The conventional pretreatment process consists of scale inhibitor (anti-scalant) and/or acid addition in combination with microfiltration. These pretreatment process are used to control scaling and protect the membrane elements; they are required for conventional reverse osmosis or NF membrane systems. The membranes can be fouled or scaled during operation. Fouling is caused by materials such as colloids and organics that are present in the raw water attaching to the membrane surface, and will reduce the productivity of the membrane. Scaling is caused by the precipitation of a sparingly soluble salt within the membrane because of the solute concentration exceeding solubility. If a raw water is excessively fouling, additional or advanced pretreatment is required.

Flux decline indicated by a reduction in membrane process productivity can be a result of scaling, colloidal fouling, microbiological fouling and organic chemical fouling. Scaling can be approximated by chemical analysis and equilibrium calculations. Fouling indices can approximate colloidal fouling. Microbiological and organic chemical fouling can only be approximated at this time by pilot testing. These mechanisms should be recognized and understood in order to develop strategies to control flux decline.

4.4.1.1 Scaling

In a membrane process salts present in the feed water are concentrated on the feed side of the membrane. This concentration process continues until saturation and a salt precipitates and scaling occurs. Scaling will reduce membrane productivity, and consequently, will limit the amount of water that may be recovered as permeate on a sustained basis. The maximum recovery is the recovery at which the limiting salt first begins to precipitate.

Limiting salts can be identified from the solubility products of sparingly soluble salts in the raw feed water. Since ionic strength increases on the feed side of the membrane, the effect of ionic strength upon the solubility products must also be considered and taken into account for these calculations. Some limiting salts may be controlled via the addition of acid and/or scale inhibitor into the feed water prior to membrane treatment. Typical sparingly soluble salts that may limit recovery in pressure-driven membrane processes include, but are not limited to: $CaCO_3$; $CaSO_4$; $BaSO_4$; $SrSO_4$; CaF_2; and SiO_2.

4.4.1.2 Colloidal Fouling

Colloidal fouling results from particles that exist in the influent which build-up on the surface of the membrane. The build-up forms a cake, which eventually is compressed, reducing flow through the membrane. Initially cake formation does not significantly reduce productivity. However, after the cake compresses, the productivity decreases, and the compressed cake must be removed. MF or UF membranes can be backwashed to remove the cake. However, RO and NF membranes require

chemical cleaning to remove the cake. Advanced pretreatment processes such as cross-flow MF and multi-media filtration should control colloidal fouling.

4.4.1.3 Microbiological Fouling

Microbiological fouling results from biological growth in the membrane element, which results in a reduction in membrane productivity or an increase in pressure drop across an element. No reliable methods have been demonstrated for prediction of biofouling. Microbiological growth can occur in the feed spacers or on the membrane surface. Microbiological growth will occur in membranes, but this growth does not always result in significant productivity loss. Advanced pretreatment processes may aid in controlling microbiological fouling.

4.4.1.4 Chemical Fouling

Chemical fouling results from the interaction of dissolved organic solutes in the feed stream with the membrane surface, which results in a reduction in membrane productivity. Chemical interaction between solute and the membrane surface will occur to some degree, but membrane productivity may not be reduced. Advanced pretreatment processes may aid in the control of chemical fouling.

4.4.2 Advanced Pretreatment

Advanced pretreatment would include unit operations that precede scaling control and static microfiltration. By definition, unit operations that precede conventional pretreatment would be advanced pretreatment. Examples of advanced pretreatment would be coagulation, oxidation followed by greensand filtration, groundwater recharge, continuous cross-flow microfiltration, multi-media filtration, and granular activated carbon (GAC) filtration.

4.4.3 Membrane Processes

The membrane process follows pretreatment. The majority of dissolved contaminants are removed in the membrane process. If the membrane scales or fouls then the productivity of the membrane system declines and eventually the membranes must be chemically cleaned to restore productivity. Cleaning frequencies for RO or NF systems average about 6 months (Taylor et al. 1990) when treating ground waters and can be as low as 1 to 2 weeks when treating a surface water with integrated membrane systems (IMS).

MF and UF membranes are sieving controlled and they do not have a low enough molecular weight cut-off (MWCO) range to reject radionuclides. However, RO and NF membranes can achieve significant radionuclide rejection because the MWCO of these membranes are low and most radionuclides cannot pass. Radon is a dissolved gas, and like carbon dioxide and hydrogen sulfide will not be removed by a membrane process. This is also the case with IOCs and SOCs. NF removes inorganic solutes from water, and this can impact the corrosivity of the permeate water.

4.4.4 Post-Treatment

Typical post-treatment unit operations can consist of disinfection, aeration, stabilization and storage. Aeration may be required to strip dissolved gases (Duranceau 1993). Stabilization may be required to

produce a non-corrosive finished water since membrane permeate can be corrosive. Alkalinity recovery is an effective process for recovering dissolved inorganic carbon (DIC) in the permeate. Alkalinity can be recovered by lowering the pH prior to membrane filtration and converting the alkalinity to CO_2, and then raising the pH of the permeate in a closed system to recover dissolved CO_2 as alkalinity. By-passing feedwater and blending it with membrane permeate is another way of stabilizing the finished water, however blending would negate the benefit of membrane treatment system to act as a barrier against contaminants.

4.4.5 Waste Disposal

In addition to post treatment, the concentrate stream from the membrane processes must be treated and/or disposed of in some manner. Effective concentrate disposal methods depend on the concentrate water quality, local regulations and site specific factors (AWWARF 1993). The handling and disposal of the wastes generated by treatment technologies removing naturally occurring radionuclides from drinking water pose concerns to the water supplier, to local and State governments and to the public at large. The potential handling hazards associated with radionuclides warrant the development of a viable membrane concentrate disposal method. Information regarding concentrate disposal options can be found in Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides (USEPA, 1990). The document first addresses the management of radionuclide wastes by first describing the potential sources of these wastes (i.e., water treatment processes). Then there is a brief review of the known information on the radionuclide composition of the associated treatment wastes. The document then describes the plausible disposal alternatives and provides background information from related programs that should assist facilities in selecting a responsible option. The following are disposal options that must be approved by the State or local government prior to implementation of a waste disposal program.

Liquid Waste Disposal

- Direct discharge into storm sewers or surface water.
- Discharge into sanitary sewer.
- Deep well injection.
- Drying or chemical precipitation.

Solid Waste Disposal

- Temporary lagooning (surface impoundment).
- Disposal in landfill.
    d) Disposal without prior treatment.
    e) With prior temporary lagooning.
    f) With prior mechanical dewatering.
- Application to land (soil spreading/conditioning).
- Disposal at State licensed low-level radioactive waste facility.

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

Bulk Rejection - Percent solute concentration retained by the membrane relative to the bulk stream concentration.

$$1 - \frac{C_p}{C_f}$$

where:

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

Bulk Solution - The solution on the high-pressure side of the membrane that has a water quality between that of the influent and concentrate streams.

Cleaning Frequency - The loss or decrease of the mass transfer coefficient (MTC) for water measures membrane productivity over time of production. Membranes foul during operation. Constant production is achieved in membrane plants by increasing pressure. Cleaning is done when the pressure increases by 10 to 15 percent. Cleaning frequency (CF) and a measurement of productivity can be determined from the MTC decline.

$$CF = \frac{\Omega K_w}{\frac{dK_w}{dt}}$$

where:

CF = cleaning frequency (days)

Ω = acceptable rate of MTC loss

dK_w/dt = rate of MTC decline (gsfd/psi-d)

Concentrate (Q_c, C_c) - One of the membrane output streams that has a more concentrated water quality than the feed stream.

Conventional RO/NF Process - A treatment system consisting of acid and/or scale inhibitor addition for scale control, cartridge filtration, RO/NF membrane filtration, aeration, chlorination and corrosion control.

Feed (Q_f, C_f) - Input stream to the membrane process after pretreatment.

Feedwater - Water introduced to the membrane module.

Field Operations Document (FOD) - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the USEPA/NSF Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

Field Testing Organization (FDO) - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the field testing organization is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of a package plant during the intense periods of testing during the study and the tasks required by the Protocol.

Flux (F_w) - Mass (lb/ft^2-day) or volume (gal/ft^2-day, gsfd, gfd) rate of transfer through membrane surface.

$$F_w = K_w [\Delta P - \Delta \Pi] = \frac{Q_p}{A}$$

where:

F_w = water flux ($M/L^2 \cdot t$)

K_w = global water mass transfer coefficient (t^{-1})

ΔP = transmembranic pressure gradient (M/L^2)

$\Delta \Pi$ = osmotic pressure gradient (M/L^2)

Q_p = permeate flow (L^3/t)

A = membrane surface area (L^2)

Fouling - Reduction of productivity measured by a decrease in the temperature normalized water MTC.

Fouling Indices - Fouling indices are simple measurements that provide an estimate of the required pretreatment for membrane processes. Fouling indices are determined from membrane tests and are similar to mass transfer coefficients for membranes used to produce drinking water. Fouling indices can be quickly developed from simple filtration tests, are used to qualitatively estimate pretreatment requirements and possibly could be used to predict membrane fouling. The silt-density index (SDI), modified fouling index (MFI) and mini plugging factor index (MPFI) are the most common fouling indices. The SDI, MFI and the MPFI are defined using the basic resistance model, and are quantitatively related to water quality and NF membrane fouling.

Some approximations for required indices prior to conventional membrane treatment are given below (Sung et. al. 1994).

Fouling Index Approximations for NF

Fouling Index	Range
SDI	< 3
MFI	< 10 s/L^2

Silt-Density Index (SDI): The SDI is the most commonly used test to predict a water's potential to foul a membrane by colloidal particles smaller than 0.45 microns. SDI is only a guide for pretreatment and is not an indication of adequate pretreatment. The SDI is a static measurement of resistance, which is determined by samples taken at the beginning and the end of the test. The SDI test is performed by timing the anaerobic hydraulic flow through a 47 mm diameter, 0.45 micron

membrane filter at a constant pressure of 30 psi. The time required for 500 mL of the feed water to pass through the filter is measured when the test is first initiated, and is also measured at time intervals of 5, 10, and 15 minutes after the start of the test. The value of the SDI is then calculated as follows (ASTM D-4189-82).

$$SDI = \left[\frac{1 - \frac{t_i}{t_f}}{t_T} \right] * 100\% \qquad \textbf{(EQUATION 2.4)}$$

where:

t_i = time to collect initial 500 mL sample

t_f = time to collect 500 mL sample at time t = T

t_T = total running time of the test; 5, 10, or 15 minutes.

If the index is below a value of 3 then the water should be suitable for reverse osmosis. If the SDI is below 3, the impact of colloidal fouling is minimized.

Modified Fouling Index (MFI): The MFI is determined using the same equipment and procedure used for the SDI, except that the volume is recorded every 30 seconds over a 15 minute filtration period (Schippers and Verdouw 1980). The development of the MFI is consistent with Darcy's Law in that the thickness of the cake layer formed on the membrane surface is assumed to be directly proportional to the filtrate volume. The total resistance is the sum of the filter and cake resistance. The MFI is defined graphically as the slope of an inverse flow verses cumulative volume curve as shown in the following equations

$$\frac{dV}{dt} = \frac{\Delta P}{\mu} \frac{A}{(R_f + R_k)}$$

$$t = \frac{\mu V R_f}{\Delta P A} + \frac{\mu V^2 I}{2 \Delta P A^2}$$

$$\frac{1}{Q} = a + MFI * V$$

where:

R_f = resistance of the filter

R_k = resistance of the cake

I = measure of the fouling potential

Q = average flow (liters/second)

a = constant

Typically the cake formation, build-up and compaction or failure can be seen in three distinct regions on a MFI plot. The regions corresponding to blocking filtration and cake filtration represent productive operation, whereas compaction would be indicative of the end of a productive cycle.

Influent - Input stream to the membrane array after the recycle stream has been blended with the feed stream. If there is no concentrate recycle then the feed and influent streams are identical.

Mass Transfer Coefficient (MTC) (K_w) - Mass or volume unit transfer through membrane based on driving force (gfd/psi).

$$K_w = \frac{Q_p}{A(\quad - \quad)}$$

where:

K_w = global water mass transfer coefficient (t^{-1})

ΔP = transmembranic pressure gradient (M/L^2)

$\Delta \Pi$ = osmotic pressure gradient (M/L^2)

Q_p = permeate flow (L^3/t)

A = membrane surface area (L^2)

Membrane Element - A single membrane unit containing a bound group of spiral wound or hollow-fiber membranes to provide a nominal surface area for treatment.

Membrane Molecular Weight Cutoff Determination - The membrane molecular weight cutoff (MWCO) of membranes a commonly used to characterize membrane rejection capability. Membrane MWCO is typically determined by measuring the rejection of different molecular weight nonionic polymers. Solute rejection is defined as:

$$\% \text{ Solute Rejection} = \left(1 - \frac{C_p}{C_f}\right) * 100\%$$

Given the narrow molecular weight bands of polyethylene glycol (PEG) solutions, these nonionic random coil polymers can be applied to membranes for MWCO estimation. Although the percent PEG rejection varies by manufacturer, 80 to 90 percent PEG rejection has been used. Neither the percent rejection nor the material is fixed except by membrane manufacturer. The standard molecular weight solutions can be measured as TOC and correlated to PEG concentration. This correlation can then be applied for assessment of PEG rejection by the membrane and subsequent MWCO determination.

Membrane Productivity - Membrane productivity will be assessed by the rate of mass transfer coefficient (MTC_w) decline over time of operation. As flux declines, a constant product can be achieved by increasing pressure to maintain a constant flux.

Net Driving Pressure (NDP): The net driving pressure (NDP) is calculated using the influent, concentrate and permeate pressure.

$$NDP = \left[\frac{(P_f + P_c)}{2}\right] - P_p -$$

where:

NDP = net driving pressure for solvent transport across the membrane (psi, bar)

P_f = feedwater pressure to the feed side of the membrane (psi, bar)

P_c = concentrate pressure on the reject side of the membrane (psi, bar)

P_p = permeate pressure on the treated water side of the membrane (psi, bar)

$\Delta\pi$ = osmotic pressure (psi)

Osmotic Pressure Gradient ($\Delta\pi$)**:** The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. In order to determine the NDP, the osmotic pressure gradient must be estimated from the influent, concentrate and permeate TDS.

$$= \left(\left[\frac{(TDS_f + TDS_c)}{2} \right] - TDS_p \right) * \left(\frac{1\,\text{psi}}{100 \frac{\text{mg}}{\text{L}}} \right)$$

where:

TDS_f = feedwater total dissolved solids (TDS) concentration (mg/L)

TDS_c = concentrate TDS concentration (mg/L)

TDS_p = permeate TDS concentration (mg/L)

Mass Transfer Coefficient (MTC_w): The MTC_w is calculated by using the permeate flow and membrane surface area.

$$F_w = \frac{Q_p}{A} = MTC_w * NDP$$

From this the MTC_w can be calculated. However, given the relationship between temperature and the viscosity of water, flux should be normalized to a standard temperature condition (25°C). These relationships should be provided by the membrane manufacturer and used to normalize the flux data set as shown below.

$$MTC_{w,\,25^\circ C} = \frac{F_{w,\,25^\circ C}}{NDP}$$

Temperature Adjustment for Flux Calculation: If manufacture does not specify a temperature correction equation the following equation may be used so that water production can be compared on an equivalent basis.

$$F_{w,\,25^\circ C} = F_{w,\,T^\circ C} * 1.03^{(25^\circ C - T^\circ C)}$$

Recovery: Recovery should also be calculated using the permeate and influent flow.

$$R = \frac{Q_p}{Q_i}$$

Using the above equations the MTC_w, normalized flux and recovery for each stage and the system can be calculated for each set of operational data and plotted as a function of cumulative operating time.

Package Plant - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

Permeate (Q_p, C_p) - The membrane output stream that has convected through the membrane.

$$Q_p C_p = Q_f C_f - Q_c C_c$$

Permeate - Water produced by the membrane process.

Permeate Flux - The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where:

J_t = permeate flux at time t (gfd, L/(h-m^2))

Q_p = permeate flow (gpd, L/h)

S = membrane surface area (ft^2, m^2)

It should be noted that only gfd and L/(h-m^2) shall be considered acceptable units of flux for this testing plan.

Pressure Vessel - A single tube or housing that contains several membrane elements in series.

Raw - Input stream to the membrane process prior to any pretreatment.

Recovery - The recovery of feedwater as permeate water is given as the ratio of permeate flow to feedwater flow:

$$\%\ \text{System Recovery} = 100 \cdot \left[\frac{Q_p}{Q_f}\right]$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_p = permeate flow (gpm, L/h)

Recycle Ratio (r) - The recycle ratio represents the ratio of the total flow of water that is used for cross-flow and the net feedwater flow to the membrane. This ratio provides an idea of the recirculation pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ratio} = \left[\frac{Q_r}{Q_f}\right]$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_r = recycle hydraulic flow in the membrane element (gpm, L/h)

Rejection (mass) – The mass of a specific solute entering a membrane system that does not pass through the membrane.

$$\left(1 - \frac{Q_p C_p}{Q_f C_f}\right)$$

Scaling Control - Controlling precipitation or scaling within the membrane element requires identification of a limiting salt, acid addition for prevention of $CaCO_3$ and/or addition of a scale inhibitor. The limiting salt determines the amount of scale inhibitor or acid addition. A diffusion controlled membrane process will concentrate salts on the feed side of the membrane. If excessive water is passed through the membrane, this concentration process will continue until a salt precipitates and scaling occurs. Scaling will reduce membrane productivity and consequently recovery is limited by the allowable recovery just before the limiting salt precipitates. The limiting salt can be determined from the solubility products of potential limiting salts and the actual feed stream water quality. Ionic strength must also be considered in these calculations as the natural concentration of the feed stream during the membrane process increases the ionic strength, allowable solubility and recovery.

Calcium carbonate scaling is commonly controlled by sulfuric acid addition however sulfate salts are often the limiting salts. Commercially available scale inhibitors can be used to control scaling by complexing the metal ions in the feed stream and preventing precipitation. Equilibrium constants for these scale inhibitors are not available which prevents direct calculation. However some manufacturers provide computer programs for estimating the required scale inhibitor dose for a given recovery, water quality and membrane. The following are general equations for the solubility products and ionic strength approximations.

Solubility Product: Calculation of the solubility product of selected sparingly soluble salts will be important exercise for the test plan in order to determine if there are operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = \gamma_A^x \left[A^{y-}\right]^x \gamma_B^y \left[B^{x+}\right]^y$$

where:

K_{sp} = solubility product for the limiting salt being considered

γ = free ion activity coefficient for the ion considered (i.e., A or B)

[A] = molal solution concentration of the anion A for sparingly soluble salt A_xB_y

[B] = solution concentration of the anion B

x, y = stiochiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient: The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log \gamma_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{\mu}$$

where:

γ = free ion activity coefficient for the ion considered (i.e., A or B)

Z_A = ion charge of anion A

Z_B = ion charge of cation B

μ = ionic strength

Ionic Strength**:** A simple approximation of the ionic strength can calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$\mu = (2.5 \cdot 10^{-5}) \cdot (TDS)$$

where:

μ = ionic strength

TDS = total dissolved solids concentration (mg/L)

Solute - The dissolved constituent (mg/L) in a solution or process stream.

Solute Rejection - Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation.

$$\%\,\text{Solute Rejection} = 100 \cdot \left[\frac{C_f - C_p}{C_f} \right] \quad (4.8)$$

where:

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

Solvent - A substance, usually a liquid such as water, capable of dissolving other substances.

Solvent and Solute Mass Balance - Calculation of solvent mass balance is performed to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the membrane system is performed to estimate the concentration of limiting salts at the membrane surface.

$$Q_f = Q_p + Q_c$$

$$Q_f C_f = Q_p C_p + Q_c C_c$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_p = permeate flow (gpm, L/h)

Q_c = concentrate flow (gpm, L/h)

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

C_f = concentrate concentration of specific constituent (mg/L)

Specific Flux - At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure shall be recorded and the specific flux calculated. The efficiency of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficiency achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow an evaluation of irreversible fouling. Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task.

Percent Recovery of Specific Flux: The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux (F_{sf}) and the initial specific flux (F_{si}) measured for the subsequent run.

$$\% \text{ Recovery of Specific Flux} = \left[1 - \frac{F_{sf}}{F_{si}}\right] * 100\%$$

where:

F_{sf} = Specific flux (gfd/psi, L/(h-m^2)/bar) at end of run (final)

F_{si} = Specific flux (gfd/psi, L/(h-m^2)/bar) at beginning of run (initial).

Percent Loss of Original Specific Flux: The loss of original specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (F_{si}) divided by the original specific flux (F_{sio}), as measured at the initiation of the first filtration run in a series.

$$\% \text{ Loss of Original Specific Flux} = \left[1 - \frac{F_{si}}{F_{sio}}\right]$$

Verification Statement - A written document that summarizes a final report reviewed and approved by NSF on behalf of the USEPA or directly by the USEPA.

Water System - The water system that operates using packaged water treatment equipment to provide potable water to its customers.

6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of package water treatment equipment utilizing NF membrane processes. Testing of NF membrane processes will be conducted by a NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a State, NSF, or EPA qualified analytical laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and FOD for removal of radionuclides.

- **Task 1: Characterization of Raw Water** – Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.
- **Task 2: Equipment Verification Testing Plan** – Operate NF membrane processes and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.
- **Task 3: Operations and Maintenance (O&M)** - Develop an O&M manual for each system submitted. The O&M manual shall characterize NF membrane process design, outline a NF membrane process cleaning procedure or procedures, and provide a concentrate disposal plan.
- **Task 4: Data Collection and Management** Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 5: Membrane Productivity** - Demonstrate operational conditions for the membrane equipment; permeate water recovery achieved by the membrane equipment; and rate of flux decline observed over an extended membrane process operation.
- **Task 6: Radioactive Chemical Contaminant (Radionuclide) Removal -** Evaluate NF membrane processes in relation to verified raw water quality. Report operating conditions.
- **Task 7: Finished Water Quality** – Evaluate the water quality produced by NF membrane processes as it relates to raw water quality and operational conditions.
- **Task 8: Quality Assurance / Quality Control (QA/QC)** – Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during NF membrane equipment Verification Testing.
- **Task 9: Cost Evaluation** - Develop O&M costs for the submitted NF membrane technology and package plant.

7.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 9) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the FOD, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in

the FOD that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the "*Protocol for Equipment Verification Testing of for Removal of Radioactive Chemical Contaminants*". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For membrane process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;
- Feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane module and may require variable strategies in anti-scalant addition and pH adjustment;
- Cold water, encountered in winter or at high altitude locations;
- High concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;
- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing program. Membrane testing conducted beyond the required 60-day testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During the testing periods, evaluation of cleaning efficiency and finished water quality can be performed concurrent with membrane operation testing procedures.

8.0 TASK 1: CHARACTERIZATION OF RAW WATER

8.1 Introduction

A characterization of raw water quality is needed to determine if the concentrations of Ra-226, Ra-228, and Uranium, or other raw water contaminants are appropriate for the use of NF membrane processes. The feed water quality can influence the performance of the equipment as well as the acceptance of testing results by Federal and State regulatory agencies.

8.2 Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of radionuclides;
- develop maximum and minimum concentrations for the contaminant; and

- develop a probable percentage of removal necessary to meet the proposed MCL.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

8.3 Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geographical Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on the NF membrane process that is being tested. The following characteristics should be reviewed and documented:

- Radium-226
- Radium-228
- Uranium
- Temperature
- pH
- TDS/Conductivity
- Total Hardness
- Calcium Hardness
- Total Organic Carbon
- Total Alkalinity
- Turbidity
- True Color
- Chloride
- Fluoride
- Sulfate
- Ammonia
- Iron
- Manganese
- Silica
- Barium
- Nitrate
- Sodium
- Potassium
- Strontium
- Phosphate
- SDI
- MFI

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized, the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

8.4 Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility of historical data. The historical water quality data can be used to determine the suitability of NF membrane processes for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the Verification Testing of the NF membrane equipment.

8.5 Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Capabilities for the removal of radionuclides. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For NF membrane processes, a complete scan of water quality parameters may be required in order to determine limiting salt concentrations, necessary for establishing pretreatment criteria.

9.0 TASK 2: EQUIPMENT VERIFICATION TEST PLAN

9.1 Introduction

The equipment verification for NF membrane processes for radionuclide removal shall be conducted by a NSF-qualified Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this NSF Plan shall be contracted with a State, NSF or EPA qualified laboratory. For information on a listing of NSF-qualified FTOs, contact NSF.

9.2 Objectives

The objective of this task is to operate the equipment provided by a manufacturer, for the conditions and time periods specified by NSF and the manufacturer.

9.3 Work Plan

9.3.1 Equipment Verification Test Plan

Table 9.1 presents the Tasks that are included in this Plan and will be included in the FOD for radionuclide removal by NF membrane processes. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing. All permeate flux values shall be reported in terms of temperature-corrected flux (normalized flux) values, as either gallons per square foot day (gsfd) at 77^{o}F or liters per square meter per hour (L(m^{2}-hr) at 25^{o}C).

In the design of the FOD, the FTO shall stipulate which pretreatments are appropriate for application before the selected NF membrane processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 9.1: Task Descriptions

No.	Task	Description
1	Characterization of Raw Water	Obtain chemical, biological and physical characterization of the raw water.
2	Test Plan	Water treatment equipment shall be operated for a minimum of 60 days per test period to collect data on water quality and equipment performance.
3	O&M	Evaluate O&M manual for process.
4	Data Management	Develop data protocol between FTO and NSF.
5	Membrane Productivity	Demonstrate operational conditions for the membrane equipment, permeate water recovery achieved by the membrane equipment, and rate of flux decline observed over an extended membrane process operation
6	Contaminant Removal	Evaluate radionuclide removal at selected set of operational conditions.
7	Finished Water Quality	Evaluate water quality at selected set of operational conditions.
8	QA/QC	Enforce QA/QC standards.
9	Cost Evaluation	Provide O&M costs of system.

9.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the package water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. In addition, the equipment should not be used for potable water production should a finished water quality parameter not comply with the requirements of the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

9.4 Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one, 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for NF membrane process performance. A full one-year testing period would also be acceptable, but is not required.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. NF membrane process testing conducted beyond the required 60-day testing may be used for fine-tuning of NF performance or for evaluation of additional

operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

9.5 Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days. If package water treatment equipment is also operated for potable water production, the data supplied to the FTO shall be evaluated with regard to compliance with National Primary Drinking Water Standards or EPA National Secondary Drinking Water Regulations.

10.0 TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for NF membrane processes to be tested for radionuclide removal shall be included in the Verification Testing evaluation.

10.1 Objectives

The objective of this task is to provide an O&M manual that will assist in operating, troubleshooting and maintaining NF membrane process performance. The O&M manual shall:

- characterize NF membrane process design;
- outline a NF membrane process cleaning procedure or procedures; and
- provide a concentrate disposal plan.

The concentrate disposal plan must be approved by the State in question for permanent installation. A fully developed concentrate disposal plan would be required because of the radionuclides that have been concentrated in the waste stream. Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

Each specific test plan will include a list of criteria for evaluating O&M information. This shall be compiled and submitted for evaluation by USEPA, NSF and technical peer reviewers. An example is provided in Table 10.2. The purpose of this O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2 O&M Work Plan

Descriptions for pretreatment, NF membrane process, and post-treatment to characterize the NF membrane system unit process design shall be developed. Membrane processes shall include the design criteria and NF membrane element characteristics. Examples of information required relative to the membrane design criteria and element characteristics are presented in Tables 10.3 and 10.4, respectively.

The NF membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals shall include cleaning frequencies greater than 6 months for no more than 15 percent productivity decline. However, it should be noted that some systems may accommodate a 20 percent MTC or flux decline. Therefore, cleaning frequency could be predicted using the equation for cleaning frequency.

Productivity decline will be determined by either normalized flux decline or normalized solvent mass transfer (MTC_w) reduction. Normalized means that the flux has been adjusted for temperature and pressure. Therefore, conditions of constant system pressure where solvent flux remains greater than 90 percent of its original value would be desired. The use of the normalized MTC_w for productivity decline would eliminate the need for constant system pressure for productivity decline determination. Should constant flux be used as an operating guideline for particles under application, then a 10 to 15 percent pressure increase would constitute criteria for cleaning.

Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions could also be analyzed for determining which constituents may have adsorbed or precipitated onto the membrane surface. Analysis of cleaning solutions can be coupled with mass balances on the same solutes monitored during operation to determine solute accrual in nanofilters. This may prove useful for establishing the mechanism of removal for some radionuclides. A cleaning efficiency evaluation is described in Section 5.0.

TABLE 10.1: NSF OPERATIONS & MAINTENANCE MANUAL CRITERIA - NF Membrane Process Package Plants

MAINTENANCE:

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- flow meters
- pressure gauges
- pumps
- motors
- valves
- chemical feeders
- mixers

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- membranes
- pressure vessels
- piping

OPERATION:

The manufacturer should provide readily understood recommendation for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments - how they should be made
- dilution of chemicals and scale inhibitors - proper procedures

Monitoring and observing operation:

- mass balance calculations
- recovery calculation

TABLE 10.1: NSF OPERATIONS & MAINTENANCE MANUAL CRITERIA - NF Membrane Process Package Plants (continued)

OPERATION (continued):

Monitoring and observing operation (continued):

- pressure losses

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- flux decline;
- no raw water (feed water) flow to plant;
- when the water flow rate through the package plant can not be controlled;
- no chemical feed;
- automatic operation (if provided) not functioning;
- no electric power; and
- sand or silt entrainment.

The following are recommendations regarding operability aspects of package plants membrane processes. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program. During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects.

- are chemical feed pumps calibrated?
- are flow meters present and have they been calibrated?
- are pressure gauges calibrated?
- are pH meters calibrated?
- are TDS or conductivity meters calibrated?
- can cleaning be done automatically?
- can membrane seals be easily replaced?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Membrane Process Test Plan.

TABLE 10.2: Requirements for Maintenance and Operability of NF Membrane Process Package Plants

MAINTENANCE INFORMATION		
Equipment	**Maintenance Frequency**	**Replacement Frequency**
membranes		
pumps		
valves		
motors		
mixers		
chemical mixers		
water meters		
pressure gauges		
cartridge filters		
seals		
piping		

OPERABILITY INFORMATION: (rank from 1 (easy) to 3 (difficult), or N/A)	
Operation Aspect	**Response**
Chemical feed pumps calibration	
Flow meters calibration	
Pressure gauges calibration	
pH meters calibration	
TDS or conductivity meters calibration	
Cleaning	
Replacement of membrane seals	
Measurement and control of flux decline	

Notes:

TABLE 10.3: NF Membrane Plant Design Criteria Reporting Items

Parameter	Value
Number of stages	
Number of pressure vessels in stage 1	
Number of pressure vessels in stage 2	
Number of elements per pressure vessel	
Recovery per stage (%)	
Recovery for system (%)	
Design flow (gpm)	
Design temperature (°C)	
Design flux (gsfd)	
Surface area per element (ft^2)	
MTC_W (gsfd/psi)	
Maximum flow rate to an element (gpm)	
Minimum flow rate to an element (gpm)	
Pressure loss per element (psi)	
Pressure loss in stage entrance and exit (psi)	
Feed stream TDS (mg/L)	
Ra-226 rejection (%)	
Ra-228 rejection (%)	
Uranium rejection (%)	

TABLE 10.4: NF Membrane Element Characteristics

Membrane manufacturer			
Membrane module model number			
Size of element used in study (e.g. 4” x 40”)			
Active membrane area of element used in study			
Active membrane area of an equivalent 8” x 40” element			
Purchase price for an equivalent 8” x 40” element ($)			
Molecular weight cutoff (Daltons)			
Membrane material / construction			
Membrane hydrophobicity (circle one)	Hydrophilic		Hydrophobic
Membrane charge (circle one)	Negative	Neutral	Positive
Design pressure (psi)			
Design flux at the design pressure (gfd)			
Variability of design flux (%)			
MTC_W (gfd/psi)			
Standard testing recovery (%)			
Standard testing pH			
Standard testing temperature (°C)			
Design cross-flow velocity (fps)			
Maximum flow rate to the element (gpm)			
Minimum flow rate to the element (gpm)			
Required feed flow to permeate flow rate ratio			
Maximum element recovery (%)			
Rejection of reference solute and conditions of test (e.g. solute type and concentration)			
Variability of rejection of reference solute (%)			
Spacer thickness (ft)			
Scroll width (ft)			
Acceptable range of operating pressures			
Acceptable range of operating pH values			
Typical pressure drop across a single element			
Maximum permissible SDI			
Maximum permissible turbidity (NTU)			
Chlorine/oxidant tolerance			
Suggested cleaning procedures			

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each membrane tested.

11.0 TASK 4: DATA COLLECTION AND MANAGEMENT

11.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, in addition to manual recording of operational parameters for the NF membrane processes on a daily basis.

11.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data to NSF for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3 Work Plan

11.3.1 Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of NF membrane process operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for three eight-hour shifts per day. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet) The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of the FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2 Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and

operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each NF membrane process test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to State, NSF or EPA qualified laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3 Statistical Analysis

For the analytical data obtained during Verification Testing, 95 percent confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0 TASK 5: MEMBRANE PRODUCTIVITY

12.1 Introduction

The removal of Ra-226, Ra-228, and Uranium from drinking water supplies is accomplished by NF membrane filtration. The effectiveness of NF membrane processes for radionuclide removal will be evaluated in this task. Membrane mass transfer coefficient, flux and recovery will be evaluated in this task. After installation of the NF process, the membranes tend to have characteristic flux decline with time until the membrane stabilizes. After this initial flux decline, the rate of flux decline will be used to demonstrate membrane performance for the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the Manufacturer in terms of a temperature-corrected flux (normalized flux) value (e.g., gsfd at 77 °F or L/(m^2hr) at 25 °C) before the initiation of the Program.

Flux decline is a function of water quality, membrane type, configuration and operational conditions. In establishing the range of operation for the membrane performance evaluations, limiting salt information should be used to define the run scenarios. The run conditions should include operating scenarios, which approach and exceed these projected limits. Subsequent water quality analysis will allow for assessment of the degree of saturation of the sparingly soluble salts in the final concentrate. The degree of saturation of the salts should then be compared to resulting membrane productivity decline. Table 12.1 is presents an example of membrane pretreatment data required to provide baseline conditions and assist in evaluating membrane productivity.

Some Manufacturers may wish to employ the NF membrane process with a pretreatment process in order to reduce flux decline and improve removal of radionuclides. Any pretreatment included in the membrane treatment system that is designed for removal of radionuclides shall be considered an integral part of the packaged NF membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

12.2 Experimental Objectives

The objectives of this task are to demonstrate:

- Operational conditions for the membrane equipment;
- Permeate water recovery achieved by the membrane equipment; and
- Rate of flux decline observed over an extended membrane process operation.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the Manufacturer, as it pertains to permeate flux, transmembrane pressure, and radionuclide removal.

12.3 Work Plan

Determination of ideal membrane operating conditions for a particular water may require as long as one year of operation. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the membrane treatment system. The Manufacturer shall evaluate flux decline. The Manufacturer shall also determine the limiting salt and identify possible foulants and scalants and use this for performance evaluation for their particular membrane equipment. The set of operating conditions shall be maintained for the 60-day testing period (24-hour continuous operation). The Manufacturer shall specify the primary permeate flux at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and “shakedown” of membrane equipment, membrane operation should be established at the flux condition to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate membrane performance under different feedwater quality conditions. For membrane processes, extremes of feedwater quality (e.g., low temperature, high TOC concentration, high turbidity, high SDI) are the conditions under which membranes are most prone to fouling and subsequent failure. At a minimum the performance of the NF membrane equipment relative to radionuclide removal shall be documented during those periods of variable feedwater conditions. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with finished water quality and if applicable, cleaning efficiency. With the exception of additional testing periods conducted at the Manufacturer's discretion, no additional membrane test runs are required for performance of cleaning efficiency and finished water quality. A continuous yearlong evaluation, although not required, may be of benefit to the Manufacturer for verification of long term trends.

12.3.1 Operational Data Collection

Measurement of membrane feedwater flow and permeate flow (recycle flow where applicable) and system pressures shall be collected at a minimum of 3 eight-hour shifts per day. Table 12.2 is an example of a daily operational data sheet for a two-stage membrane system. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific. Measurement of feedwater temperature to the membrane shall be made along with these three daily measurements in order to provide data for normalizing flux with respect to temperature.

Water quality should be analyzed from the same locations identified for TDS in Table 12.2 prior to start-up and then every two weeks for the parameters identified in Table 12.3, except for each radionuclide, which will be monitored weekly. Power costs for operation of the membrane equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. In addition, measurement of power consumption and chemical consumption shall be quantified by recording such items as day tank concentration, daily volume consumption and unit cost of chemicals.

12.3.2 Feedwater Quality Limitations

The characteristics of feedwater used during each 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the membrane flux and recovery data for each period. Accurate reporting of such feedwater characteristics are critical for the Verification Testing Program, as these parameters can substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of specific radionuclide removals over time for each 60-day test period.
- Plot graph of NDP over time for each 60-day test period.
- Plot graph of TDS over time for each 60-day test period.
- Plot graph of specific flux normalized to 25°C over time for each 60-day test period.

- Plot graph of MTC_w over time for each 60-day test period.
- Plot graph of recovery over time for each 60-day test period.

TABLE 12.1: NF Membrane Pretreatment Data

Foulants and Fouling Indices of the Feed Water Prior to Pretreatment	
Alkalinity (mg/L of $CaCO_3$)	
Ca Hardness (mg/L of $CaCO_3$)	
LSI	
Dissolved iron (mg/L)	
Total iron (mg/L)	
Dissolved aluminum (mg/L)	
Total aluminum (mg/L)	
Fluoride (mg/L)	
Phosphate (mg/L)	
Sulfate (mg/L)	
Calcium (mg/L)	
Barium (mg/L)	
Strontium (mg/L)	
Reactive silica (mg/L as SiO_2)	
Turbidity (NTU)	
SDI	
Pretreatment Processes Used Prior to Nanofiltration or Reverse Osmosis	
Pre-filter exclusion size (µm)	
Type of acid used	
Acid concentration (units)	
mL of acid per L of feed	
Type of scale inhibitor used	
Scale inhibitor concentration (units)	
mL of scale inhibitor per L of feed	
Type of coagulant used	
Coagulant dose (mg/L)	
Type of polymer used during coagulation.	
Polymer dose (mg/L)	

TABLE 12.2: Daily Operations Log Sheet for a Two-Stage Membrane Pilot Plant

Date:

Parameter	Shift 1	Shift 2	Shift 3
Time			
Initial			
Feed			
Q_{feed} (gpm)			
TDS_{feed} (before pretreatment) (mg/L)			
TDS_{feed} (after pretreatment) (mg/L)			
P_{feed} (psi)			
pH_{feed} (before pretreatment)			
pH_{feed} (after pretreatment)			
T_{feed} (°C)			
Permeate - Stage 1			
$Q_{p\text{-}S1}$ (gpm)			
$TDS_{p\text{-}S1}$ (mg/L)			
$P_{p\text{-}S1}$ (psi)			
Concentrate - Stage 1			
$Q_{c\text{-}S1}$ (gpm)			
$TDS_{c\text{-}S1}$ (mg/L)			
$P_{c\text{-}S1}$ (psi)			
$T_{c\text{-}S1}$ (°C)			
Permeate - Stage 2			
$Q_{p\text{-}S2}$ (gpm)			
$TDS_{p\text{-}S2}$ (mg/L)			
$P_{p\text{-}S2}$ (psi)			
Concentrate - Stage 2			
$Q_{c\text{-}S2}$ (gpm)			
$TDS_{c\text{-}S2}$ (mg/L)			
$P_{c\text{-}S2}$ (psi)			
Finished			
Q_{fin} (gpm)			
TDS_{fin} (mg/L)			
Recovery (Q_{fin}/Q_{feed}) (%)			
Recycle			
$Q_{recycle}$ (gpm)			

TABLE 12.3: Operating and Water Quality Data Requirements for Membrane Processes

Parameter	Sampling Frequency
Feed Water Flow	3 * Daily
Permeate Water Flow	3 * Daily
Concentrate Water Flow	3 * Daily
Feed Water Pressure	3 * Daily
Permeate Water Pressure	3 * Daily
Concentrate Water Pressure	3 * Daily
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Costs (Kwh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Independent check on pressure gages	Weekly
Verification of chemical dosages	Monthly
Feed Water and Finished Water Characteristics	
Radium-226	Weekly
Radium-228	Weekly
Uranium	Weekly
Gross Alpha and Beta Emitters	Weekly
Temperature	3 * Daily
pH	3 * Daily
TDS/Conductivity	3 * Daily
Turbidity	Every two weeks
True Color	Every two weeks
Total Organic Carbon	Every two weeks
UV Absorbance (254 nm)	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
Sodium	Every two weeks
Chloride	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Sulfate	Every two weeks
Fluoride	Every two weeks
Silica	Every two weeks
Ammonia	Every two weeks
Potassium	Every two weeks
Strontium	Every two weeks
Barium	Every two weeks
Nitrate	Every two weeks
TTHM	Every two weeks
THAA	Every two weeks
TOX	Every two weeks

13.0 TASK 6: FINISHED WATER QUALITY

13.1 Introduction

Water quality data shall be collected for the raw and finished water as provided previously in Table 12.3. (Note, in some instances sampling concentrate water quality may be required because detection limits may be too low for a specified parameter.) At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the NF membrane equipment should be proven and reported in the FOD.

13.2 Objectives

The objective of this task is to verify the Manufacturer claims. A list of the minimum number of water quality parameters to be monitored during equipment verification testing has been provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the FOD.

13.3 Work Plan

The FOD shall identify the treated water quality objectives to be achieved in the Statement of Performance Capabilities of the equipment to be evaluated in the Verification Testing Program. The FOD shall also identify in the Statement of Performance Capabilities the radionuclide that shall be monitored during equipment testing. The Statement of Performance Capabilities prepared by the FOD shall indicate the range of water quality and operating conditions under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the NF Membrane Process Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this NF Membrane Process Plan is oriented towards removal of Ra-226, Ra-228, and uranium, the Manufacturer may want to look at the treatment systems removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A State, NSF or EPA qualified analytical laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 13.1. The analytical methods utilized in this study for on-site monitoring of raw and finished water qualities are described in Quality Assurance/ Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the State, NSF or EPA qualified laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radium-226	7500-Ra	903.1
Radium-228	7500-Ra	---
Uranium	7500-U	908.0
Gross Alpha and Beta Emitters	7110	900.0
Temperature	2550	170.1
pH	4500-H^+	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
True Color	2120	110.2
Total Organic Carbon	5310	415.2
UV Absorbance (254 nm)	5910	---
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Sodium	3500-Na	273.1
Chloride	4500-Cl^-	325.1
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Sulfate	4500-SO_4^{-2}	375.4
Fluoride	4500-F^-	340.1
Silica	4500-SiO_2	370.1
Ammonia	4500-NH_3	350.2
Potassium	3500-K	256.1
Strontium	3500-Sr	200.7
Barium	3500-Ba	208.1
Nitrate	4500-NO_3^-	352.1
TTHM	5710	551
THAA	5710	552
TOX	5320	1648

3) AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

4) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

13.4 Analytical Schedule

13.4.1 Removal of Radioactive Chemical Contaminants

During the steady-state operation of each membrane testing period, radionuclide mass balances shall be performed on the membrane feed, permeate and concentrate water in order to determine the radionuclide removal capabilities of the membrane system.

13.4.2 Feed and Permeate Water Characterization

At the beginning of each membrane testing period, the raw water, permeate and in some cases the concentrate water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 12.3.

13.4.3 Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of membrane equipment testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radionuclides and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

13.4.4 Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.3 are critical for the Verification Testing Program, as these parameters can substantially influence membrane performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radionuclides.
- Water quality and removal goals specified by the Manufacturer.

14.0 TASK 7: CLEANING EFFICIENCY

14.1 Introduction

There are certain types of foulants scale that pose an immediate threat to the operational integrity of a membrane process. Examples of scale include calcium carbonate scale and silica or sulfate scale. The following guidelines can be used with the normalized performance data to determine the maximum fouling to allow prior to cleaning the system:

a. 10-15 percent decrease in the normalized permeate flow rate

b. 10-15 percent increase in the normalized system differential pressure

c. Decrease in the salt rejection for a constant feed water salinity

Should scaling or fouling occur during or following the test runs, the membrane equipment shall require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the membrane during each specified test period. In the case where the membrane does not fully reach the operational criteria for fouling as specified by the Manufacturer, chemical cleaning shall be performed after the 30 days of operation, with a record made of the operational conditions before and after cleaning.

The membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals should include cleaning frequencies once every 6 months for no more than 10 percent productivity decline for ground water sources. Productivity goals should include cleaning frequencies once per month for no more than 10 percent productivity decline for surface water sources, if applicable.

Either normalized flux decline or solvent mass transfer (MTCw) reduction will determine productivity decline. Therefore, conditions of constant system pressure where solvent flux remains greater than 90 percent of its original value would be desired. For a constant flux system, a 10 percent increase in pressure would serve as a basis for cleaning. The use of the normalized MTC_w for productivity decline would eliminate the need for constant system pressure for productivity decline determination. Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions should also be analyzed to determine which constituents might have been removed from the membrane surface during cleaning.

14.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning to the membrane systems. The intent of this task is to confirm that standard Manufacturer recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the Manufacturer recommendations; this task is considered a "proof of concept" effort, not an optimization effort.

14.3 Work Plan

The membrane systems may become fouled during the membrane test runs. These fouled membranes shall be utilized for the cleaning assessments herein. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer and vary according to identified foulants or scale. After each chemical cleaning of the membranes, the system shall be restarted and the returned to the operating condition being tested.

The Manufacturer shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals

- hydraulic conditions of cleaning
- duration of each cleaning step
- chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed

14.4 Recommended Disposal Procedures

Methods of disposal of membrane concentrate include the wastewater treatment plant, spray irrigation, deep well injection or discharge to a surface water through the National Pollutant Discharge Elimination System (NPDES). However radionuclides are considered a potentially hazardous waste and the effluent must be monitored since it is concentrated. The concentrate disposal may require other State and/or federal permits. In addition, a description of all cleaning equipment and anticipated cleaning chemical waste streams and their operations shall be described and included in the O&M manual.

14.5 Analytical Schedule

14.5.1 Sampling

The pH of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure. Conductivity and turbidity should also be used to monitor flush periods.

14.5.2 Operational Data Collection

Flow and pressure data shall be collected before system shutdown due to membrane fouling; flow and pressure data shall also be collected after chemical cleaning.

15.0 TASK 8: QUALITY ASSURANCE/QUALITY CONTROL

15.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the NF membrane process equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

15.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

15.3 QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quantity data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

15.3.1 Daily QA/QC Verification

- Chemical feed pump flow rates (check and verify components)
- On-line conductivity meters (check and verify components)
- On-line pH meters (check and verify components)

15.3.2 Monthly QA/QC Verification

- Chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line conductivity meters (recalibrate)
- On-line flow meters/rotometers (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

15.4 Analytical Methods

Use of either bench-top field analytical equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 13.1 lists AWWA and EPA standard methods of analysis.

16.0 TASK 9: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of NF membrane processes over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. The equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. Design parameters are summarized in Table 16.1. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons for Verification Testing purposes.

Operation and maintenance (O & M) costs realized in the equipment Verification Test may be utilized for calculating cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical Dosage, and
- Equipment Replacement Frequency.

The O & M costs will vary based on geographic location.

O & M costs should be provided for each membrane process that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 16.2.

Table 16.1: Design Parameters for Cost Analysis

Design Parameter	Specific Utility Values
Raw water feed rate(mgd)	
Total required plant production rate(mgd)	
By-pass flow rate (mgd)	
Required membrane train capacity (mgd)	
High/Low plant feed water temperature (°C)	
Average Flux (gsfd/psi)	
Maximum Flux (gsfd/psi)	
Average cleaning frequency (days)	
High/Low feed TDS (mg/L)	

Table 16.3: Operations and Maintenance Cost

Cost Parameter	Specific Values	
Labor rate + fringe ($/personnel-hour)		
Labor overhead factor (% of labor)		
Number of O&M personnel hours per week		
Electric rate ($/kWh)		
Membrane replacement frequency (%/year)		
Chemical Dosage (per week)		
O&M cost ($/Kgal)		
	Dose	Bulk Chemical Cost
Chlorine (Disinfectant)		
Sulfuric acid (Pretreatment)		
Alum (Pretreatment)		
Hydrochloric acid (Pretreatment)		
Scale inhibitor [2](Pretreatment)		
Caustic (Post-treatment)		
Sodium hydroxide (Membrane cleaning)		
Phosphoric acid (Membrane cleaning)		

[1]Information for cleaning chemicals and pretreatment chemicals (such as alum) should also be provided in this table. For cleaning agents, the concentration of the cleaning solution used to clean the membranes should be reported as the chemical dosed.

[2]Report the product name and manufacturer of the specific scale inhibitor used.

17.0 SUGGESTED READING

APHA, AWWA, and WEF. Standard Methods for the Examination of Water and Wastewater, 18th Edition, Washington D.C.

Atoulikian, Richard G. "Proper Design of Radon Removal Facilities for Cost-Effective Treatment." Journal NEWWA. December 1997.

AWWARF. Membrane Concentrate Disposal. Denver, CO, 1993.

Clifford, Dennis, et al. "Evaluating Various Adsorbents and Membranes for Removing Radium from Groundwater". Journal AWWA – Research and Technology, July 1988.

Cothern, C. Richard, and Rebers, Paul A. Radon, Radium and Uranium in Drinking Water. Lewis Publishers, Chelsea, MI 1990.

Deininger, Rolf A. "Monitoring for Radon in Water." Journal AWWA.

Dixon, Kevin L., Lee, Ramon G., Smith, James and Zielinski, Paul "Evaluating Aeration Technology for Radon Removal." Journal AWWA - Research and Technology, April 1991.

Dixon, Kevin L. and Lee, Ramon G., "Occurrence of Radon in Well Supplies." Journal AWWA - Management and Operations, July 1988.

Dzombak, David A., Roy, Sujoy B. and Fang, Hung-Jung, "Air-Stripper Design and Costing Computer Program." Journal AWWA - Management and Operations, October 1993.

Duranceau, S.J. "Membrane Process Post-Treatment." Supplement to AWWA Seminar Proceedings: Membrane Technology Conference. Baltimore, MD, 1993.

Freiburger, Eric J., Jacobs, Timothy L. and Ball, William P., "Probabilistic Evaluation of Packed-Tower Aeration Designs for VOC Removal." Journal AWWA - Research and Technology. October 1993.

Graves, Barbara, Radon in Ground Water, Lewis Publishers/NWWA Conference, Chelsea, MI 1987.

Hand, David W., Crittenden, John C., Gehin, Joseph L. and Lykins, Jr., Benjamin W., "Design and Evaluation of an Air-Stripping Tower for Removing VOCs from Groundwater." Journal AWWA - Research and Technology, September 1986.

Hofman, J. A. M. H., Kruithof, J. C., Noij, Th. H. M. and Schippers, J. C. "Removal of Pesticides and Other Contaminants with Nanofiltration." H_2O. March 1993.

Kinner, Nancy E., Malley, Jr., James P., Clement, Jonathan A. and Fox, Kim R., "Using POE Techniques to Remove Radon." Journal AWWA - Research and Technology, June 1993.

Lowry, Jerry D., "Measuring Low Radon Levels in Drinking Water Supplies." Journal AWWA - Research and Technology, April 1991

Lowry, Jerry D., Sylvia B. "Radionuclides in Drinking Water Supplies." Journal AWWA - Research and Technology, July, 1988.

Martins, K.L., "Practical Guide to Determine the Impact of Radon and Other Radionuclides on Water Treatment Processes." Water Scientific Tech. 26:1255-1264, Great Britain 1992.

Parrotta, Marc J., "Radioactivity in Water Treatment Wastes: A USEPA Perspective." Journal AWWA - Management and Operations, April 1991.

Pontius, Frederick W. and Paris, David B., "Congress to Decide Fate of Radon Standard." Journal AWWA - Legislation/Regulation, January 1994.

Rand, Peter W., Lacombe, Eleanor H. and Perkins, Jr., W. Dana, "Radon in Homes Following Its Reduction in a Community Water Supply." Journal AWWA - Research and Technology, April 1991.

Sorg, T.J., et al.. "Removal of Radium-226 from Sarasota County Florida, Drinking Water by Reverse Osmosis". Journal AWWA - Research and Technology, April 1980.

Sung, L. K., Morris, K. E. and Taylor J. S. "Predicting Colloidal Fouling," International Desalination and Water Reuse Journal. November/December, 1994.

Takigawa, D. Y., Metcalfe, P. F., Chu, H. C., Light, W. G., Murrer, J. and Holden, P. "Ultra-Low Pressure Reverse Osmosis Membranes." Proceedings 1995 Membrane Technology Conference. Reno, NV, 1995.

Taylor, J.S., L.A. Mulford, S.J. Duranceau and W.M. Barret. "Cost and Performance of a Membrane Pilot Plant." JAWWA. November, 1989.

Taylor, J.S., S.J. Duranceau, W.M. Barrett, and J.F. Goigel. Assessment of Potable Water Membrane Applications and Research Needs. Denver: AWWA Research Foundation. 1990.

Taylor, J.S., J.A.M.H. Hofman, S.J. Duranceau, J.C. Kruithof and J.C. Schippers. "Simplified Modeling of Diffusion Controlled Membrane Systems." J. Water, SRJ-Aqua. May, 1994.

USEPA. Multimedia Risk and Cost Assessment of Radon. Report to the United States Congress on Radon in Drinking Water. USEPA #811-R-94-001, March 1994.

Weber, W.J. Physicochemical Processes for Water Quality Control. New York: John-Wiley & Sons. 1972.

CHAPTER 4

NSF EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF RADIOACTIVE CHEMICAL CONTAMINANT BY AIR-STRIPPING TECHNOLOGIES

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List of Abbreviations

ETV	Environmental Technology Verification
FOD	Field Operations Document
FTO	Field Testing Organization
gpm/sf	gallons per minute per square foot
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
NSF	NSF International
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
rpm	revolutions per minute
% RSD	percent relative standard deviation
SDWA	Safe Drinking Water Act
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WSWRD	Water Supply and Water Resources Division

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Testing Verification Plan (Plan) for evaluation of air stripping technologies to be used within the structure provided by NSF's "*Protocol for Equipment Verification Testing of the Removal of Radioactive Chemical Contaminants by Packaged and/or Modular Drinking Water Treatment Systems* . This Plan is to be used as a guide in the development of the Field Operations Document (FOD) for testing of air-stripping process equipment to achieve removal of radionuclides.

In order to participate in the equipment verification process for air-stripping processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of a FOD. The FTO shall clearly specify in its FOD the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The FOD should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the FOD should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of radionuclides present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Capabilities (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters, or alternatively established one based upon compliance with drinking water standards. For example, the Manufacturer could include in the FOD a Statement of Performance Capabilities that would achieve compliance with maximum contaminant levels (MCLs) stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for a specific water quality parameter. The experimental design of the FOD shall be developed to address the specific Statement of Performance Capabilities established by the Manufacturer. Each FOD shall include all of the included tasks, Tasks 1 to 8.

2.0 INTRODUCTION

Air-stripping processes are currently in use for a number of water treatment applications ranging from removal of hydrogen sulfide, volatile organic carbons and radon.

In order to establish appropriate operations, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Prefiltration processes ahead of air-stripping systems are generally required to remove particulate material and to ensure provision of high quality water to the air-stripping systems. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the air-stripping process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of air-stripping process at all times during the Equipment Verification Testing Program.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Capabilities must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Capabilities that may be verified in this testing. Examples include two statements shown in Table 3.1:

For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided:

- percent removal of the targeted radionuclides;
- rate of treated water production;
- recovery;
- feedwater quality regarding pertinent water quality parameters;
- temperature;
- concentration of target radionuclide; and
- other pertinent water quality and operational conditions.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities.

Table 3.1: Example Statements of Performance Capabilities for Radionuclide Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Radionuclide Removal	This packaged plant is capable of achieving 90 percent removal of radon during a 60-day operation period at an air to water ratio of 30, and a water loading rate of 25 gal/sf-min (temperature between 20 and 25 °C) in feedwaters with radon concentrations less than 25 pCi/L and total hardness concentrations less than 150 mg/L.
Regulatory Compliance	NA*

* Radon not regulated at this time

This NSF Equipment Verification Testing Plan is broken down into 8 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan.

4.0 BACKGROUND

This section provides an overview of the literature review related to radionuclide regulations, health effects, and contaminant removal by air-stripping technologies, and air-stripping technology design. These items will assist in the following:

- Identifying the various radionuclide contaminants;
- Identifying the radionuclides that can be removed by various air-stripping technologies;
- Defining various air-stripping technologies capable of removing radionuclides;
- Defining air-stripping technologies; and
- Describing the mechanisms that will help in qualifying and quantifying the removal efficiency of the air-stripping technology tested.

4.1 Regulatory Review and Health Effects

The passage of the Safe Drinking Water Act of 1974 (SDWA) required the establishment of recommended maximum contaminant levels (MCLs) for compounds that were deemed undesirable for consumption in public water supplies. Since that time there has been a growing awareness of the need for the control and removal of chemical contaminants from potable drinking water supplies. The 1986 Safe

Drinking Water Act (SDWA) Amendments authorized the National Primary Drinking Water Regulations and required that the USEPA set such regulations on 83 contaminants including radionuclides.

Currently, the only radionuclides that are regulated include radium-226, radium-228, and alpha and beta emitters. Other radionuclides that are being considered for regulation include radon and uranium. The equipment verification tests will evaluate various technologies for the removal of radionuclides. The radionuclides that will be considered during the evaluation process are listed in Table 4.1 with their current regulatory MCLs.

TABLE 4.1: Radionuclides and Current Regulations

Radionuclides	Current MCL
Radium-226 & 228 Combined	5 pCi/L
Alpha Emitters	15 pCi/L
Beta Emitters	4 mrem/year
Radon	withdrawn
Uranium	0.02 mg/L (proposed)

In July 1991 the USEPA proposed a new rule for radionuclides in drinking water supplies (Federal Register Citation 56 GR 33050, Phase III Rule). More than 600 public comments submitted on the proposed rule were evaluated by the USEPA. Although a court deadline of April 1993 existed for the issuance of the final rule, the USEPA has delayed this deadline due to resource constraints.

The Phase III Rule is proposed to include MCLs of 0.02 mg/L for uranium and the MCL for radon has been withdrawn at this time. The expected Phase III Rule MCL of 20 pCi/L for combined radium-226 and radium-228 has also been withdrawn maintaining the current combined radium MCL at 5 pCi/L. Radium will very likely be separated and the radium MCL's may be more stringent particularly addressing radium-224. In order to minimize risks to human health, the exposure levels to these compounds must be reduced to the lowest level that is both technologically and economically feasible.

The chronic health hazards associated with the presence of radionuclides in drinking water have become a major concern of United States governmental agencies in more recent times. Radium is considered a bone seeker as it accumulates in the same organs as calcium. The ingestion of radium may lead to the development of abnormalities, cancer, or death. The lungs, myeloid stem cells, and bones of humans are particularly sensitive to such exposure. Diseases that maybe associated with radon in drinking water include stomach cancer from ingestion of drinking water, and lung cancer from inhalation of radon decay products released during household use of water. Associations of radon with other forms of cancer are considered negligible. Uranium has been shown to be carcinogenic and toxic to kidneys.

4.2 Definitions for Various Radionuclides

4.2.1 Radium

Radium (Ra) is a naturally occurring radioactive element. There are two radium isotopes that are commonly found in groundwater. These isotopes include Ra-226, an alpha emitter that is part of the Uranium decay series, and Ra-228, a beta emitter that is part of the Thorium decay series. Radium is an alkaline earth metal chemically similar to calcium, barium, and strontium. It has a low solubility and does not form any soluble complexes that enhance its dissolution into groundwater. The minute mass that is present can only be detected as activity. The current MCLs for the radium isotopes were discussed previously.

4.2.2 Radon

Radon (Rn) is a naturally occurring noble gas that is an alpha emitting radionuclide. Radon is a chemically inert decay product of the Uranium series and is the immediate decay product of Ra-226. Radon is a noble gas, very mobile, and has a short half-life of just less than four days. Radon is only found in groundwater sources of water supply since it originates in the ground and naturally degasses from surface waters. The activity of radon in water and air is generally higher than that of other radionuclides. Radon in the public water supply enters a customer's home through the distribution system and is released into the indoor air when the water is used for household purposes such as washing and cleaning. Radon is removed using air-stripping processes. As mentioned previously, there is currently no MCL for Radon.

4.2.3 Uranium

Uranium (U) is a naturally occurring radioactive element that is can be found in ground and surface water supplies. There are three common alpha emitting isotopes of Uranium that include U-235 in the Actinium decay series, and U-234 and U-238 in the Uranium decay series. Uranium is less active than radium, and is generally found in natural waters in a complex ionic form, that varies with pH. As mentioned previously, there is currently no MCL for Uranium.

4.2.4 Removal Processes

Water supply systems that use sources that contain radionuclide concentrations above future MCLs will need to implement treatment techniques to comply with future regulations. Treatment processes that are available for the removal of radionuclides include, but are not limited to, cation and anion exchange resins, zeolites, adsorptive media, reverse osmosis membranes, and air stripping.

This Plan discusses the use of air-stripping technologies for the removal of radionuclides. Air-stripping is a water treatment technique utilized for the removal of contaminant gases from water. Since radon is the only radionuclide that is a naturally occurring gas, this Plan will be directed towards the removal of radon. The following section discusses the various air-stripping technologies available for the removal of radon.

4.3 Radon Removal by Air Stripping Technologies

Aeration or air-stripping involves the transfer of radon from the water phase to the gas phase. The mass transfer from the liquid phase to the gas phase occurs over the liquid-gas interface in the direction of decreased concentration. There are two main classifications of aeration. They include gas dispersion in water and water dispersion in gas. Diffused aeration is an example of gas dispersion in water, and packed tower aeration is an example of water dispersion in gas.

One of the most integral components to the selection and design of an air-stripping device for the removal of a contaminant is Henry's constant for that contaminant. Henry's Law states that when gas and water are at equilibrium, the concentration of a substance in the gas phase is proportional to the concentration of the substance in the liquid phase. Therefore, the greater the proportional constant of a gas, the more easily that gas can be removed from solution by air stripping. This is because the mass transfer of gas moves in the direction of decreased concentration until an equilibrium state is reached. Conversely, those gases with a low proportional constant of the gas tend to accumulate in the aqueous phase. This proportional constant is known as Henry's constant.

Henry's constant for radon is estimated to be 2,260 in water at 20^{o}C and 1 atm of pressure. This constant is considered relatively high, and therefore, the removal of radon from a raw water supply using air stripping should occur fairly quickly. Henry's constants for radon and other common gases are listed in Table 4.2. Henry's constants may vary greatly with temperature and therefore testing or operating conditions should be reviewed carefully when designing air-stripping equipment.

TABLE 4.2: Henry s Constants for Selected Gases in Water at 20^{o}C and 1 atm of Pressure

Gas	Henry's Constant (atm)
Radon	2,600
Vinyl Chloride	355,000
Oxygen	43,000
Carbon Dioxide	1,510
Chlorine	585
Hydrogen Sulfide	515
Benzene	240
Chloroform	170
Bromoform	35

The efficiency of radon removal by air-stripping will depend primarily on the air to water flow rate ratio, the mass transfer coefficient and the water temperature, and to a lesser extent on the air temperature. Water treatment by aeration has been historically utilized for the removal of volatile organic carbon, carbon dioxide and hydrogen sulfide. It is also considered a cost effective treatment method for the

removal of radon from drinking water supplies. There are several types of air-stripping technologies that are available for the removal of radon. They are as follows:

- packed tower aeration;
- multistaged diffused bubble aeration;
    - spray jet aeration
    - tray aeration
    - spray aeration
- induced-draft towers; and
- venturi in-line devices.

The technologies that are described in this plan include packed tower aeration, multistaged diffused bubble aeration, and spray jet aeration. These air-stripping technologies are typically followed by chemical injection for disinfection.

4.3.1 Packed Tower Aeration

Packed tower aeration is an example of water dispersion in gas. Packed towers are generally vertical cylindrical columns. Mass transfer in a packed tower is achieved by counter-current or co-current flow, with counter-current flow being more effective. With counter-current flow raw water is pumped to the top of the tower(s) and cascades by gravity over the surface of the packing. At the same time, air is forced into the bottom of the tower and blown upward through the packing. The tower packing can be fixed or randomly packed media of various shapes, sizes, and material. The packing material disrupts the flow of water into small droplets, and therefore continually generates air-water interfaces. Air stripping towers have been found to be most applicable for water treatment facilities with flows greater than 300 to 500 gpm, but can be also applicable at lower flows.

The water is collected at the bottom of the column in a clearwell, and then pumped to subsequent treatment facilities, or disinfected for distribution. The gasses that are blown off from the tower are discharged to the atmosphere since it is not feasible to treat radon in the air stream. This would depend on the concentration of radon and other undesirable gases in the raw water source, and the local regulations that govern the release of hazardous or odiferous gases to the atmosphere. Tower height may be a major disadvantage to the packed tower technology if the facilities require significant tower height, and are located in residential areas.

4.3.2 Multistaged Bubble Aeration

Multistaged bubble aeration is a form of diffused aeration. These aeration devices are compact and have lower profiles than packed towers. The facilities consist of a vessel with several compartment stages. Water enters the box horizontally as air is diffused from aerators on the bottom of each stage. The diffusers are designed to provide uniform distribution of air.

The aeration vessels are typically equipped with a removable top for cleaning and maintenance. The blowers are generally mounted on a nearby wall or on the floor. The gasses that are vented from the

diffused aeration process can be discharged to the atmosphere. These aerators are typically most applicable for smaller flows less than 1,000 gpm.

4.3.3 Spray Jet Aeration

Jet aeration is a diffused aeration process that combines liquid pumping with air diffusion. Jet aeration can be provided in a reservoir, tank or tower. Proper air dispersion and water distribution is integral to proper design of this air-stripping technology. The liquid pumping system recirculates the water in the given basin while injecting it with compressed air through a nozzle assembly. The spray jet unit provides for the water to enter the jet nozzle unit at right angles to the body of the unit through carefully designed orifices. This creates a vacuum effect through the rear of the unit. The jet aerator produces a pressurized water stream that results in a violent mixing of the water and air within the spray jet unit, resulting in the stripping of gases. Design of these type aerators will greatly depend on manufacturer data and information regarding the jet aerator units.

Modifications to jet aeration technology can include the varying of flow rates to provide varying air to water ratios. Adjusting the size of the orifices on the jet aerator does this. Spray jet aerators may also operate in single or multiple pass modes where the water supply can be passed through the aerator from one to several times.

4.4 Air Stripping Technology Design Considerations

Although the equipment for the various air-stripping technologies vary greatly, the design considerations for the technologies are similar. These design considerations include, but are not limited to:

- Water and air flow rates
- Surface area at the water/air interface (mass transfer coefficient)
- Water and air temperature
- Henry's constant for radon
- Water quality

Pretreatment, prior to air-stripping may be necessary to provide removal of iron, manganese, or to reduce the scaling potential. Also, calcium carbonate scaling with the removal of carbon dioxide is a potential problem with aeration applications

4.4.1 Packed Tower Aeration

The major design components to be considered for packed tower aerators include:

- volumetric air-water ratio;
- water and air loading rates;
- packing material;
- size and depth;
- column diameter;

- gas pressure drop; and
- Henry's constant of the contaminant(s) to be removed.

The air to water ratio can range from 10:1 to 5,000:1 for gas stripping techniques. For the removal of radon, typically an air to water ration will range from 10:1 to 30:1. However, the air to water ratio may be more limited or constrained by the removal of another contaminant from the raw water supply. Hydraulic loading rates for the removal of radon typically range from 20 to 30 gallons per minute per square foot (gpm/sf). Air delivery can be accomplished using forced draft or induced draft aeration.

The packing material should be designed to provide a maximum amount of surface area for water to contact. At the same time the material should be chosen and designed to minimize impedance to the air flow. Random media can be shaped as discs, spheres, or barrels, while structured packing generally consists of rigid plastic sheets fused together. The packing material may require periodic cleaning with acid depending on the raw water quality. A packing support plate is used to hold the packing material in place.

Tower design can be aided by the use of mass transfer equations. Literature research documents the use of relating packing height (Z), height of transfer unit (HTU), number of transfer units (NTU), and stripping factors (R) for packed tower design. HTU is a measurement of the mass transfer efficiency, NTU is a measurement of the movement of a compound in solution to the gas phase, and R represents an equilibrium parameter. These relationships assume steady-state operations, dilute solutions, and chemical equilibria.

Tower diameter and pressure drop for a packed tower can be estimated using pressure drop curves as developed by Eckert. The curves by Eckert relate pressure drop to gas and liquid loading rates. There has also been arithmetic representation of the Eckert plot performed by Prahl. These graphical and arithmetic aids are useful in the design of packed towers. There are also several computer programs available for the sizing of packed tower aerators.

Henry's constant for radon, which was previously discussed, can be used to determine the rate of volatilization from water into clean air. Therefore, Henry's constant is an important design parameter that should be considered for the design of packed towers. It should be noted that published values of Henry's constant for radon may vary based on the constant's dependence on temperature.

4.4.2 Multistaged Bubble Aeration

The design of a multistaged bubble aeration system is based on mass transfer efficiency. This design utilizes the air to water ratio, water depth, and diffuser orifice size. A typical air to water ratio for radon removal with multistaged bubble aeration is 6:1 to 30:1, depending on the amount of removal desired. The power costs for this diffused system will be greater than that of an air stripper, because the air is discharged under pressure to the diffusers submerged in water.

The number and spacing of diffusers is generally determined based on the capacity of an individual diffuser, the geometry of the basin, and the desired level of mixing necessary for contaminant removal. Diffused multistaged aeration units can be manifolded for the treatment of larger capacities

4.4.3 Spray Jet Aeration

The design of spray aeration devices may be approached using the mass transfer coefficient and the transfer unit approach discussed for packed tower aeration. This method, however, is not completely valid as the mass transfer coefficient that is used represents an average value based on basin or tower height. Therefore, design of a spray jet aeration system cannot be performed for precise removal. However, the design approach using the average mass transfer coefficient may be used to approximate spray aeration removal efficiency.

The manufacturer should provide flow capacities for the jet nozzles for a large range of pressure drops and orifice sizes. The flow rate through a nozzle is proportional to the square root of the pressure. Spray jet nozzles may be prone to clogging and erosion corrosion.

The design of the spray chamber should consider the orientation and location of the air inlets. The inlets should be designed to avoid high inlet velocities and turbulence. If air velocities are too high there may be a substantial loss of water in the system. Mist eliminators can be used to reduce liquid loss in the chamber. The chamber is typically designed for a pressure loss of approximately 1 inch of water.

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

- **Equipment** - A package drinking water treatment system or a modular component of a package drinking water system.

- **Manufacturer** - A business that makes and/or sells package plant equipment and/or modular systems. The role of the manufacturer is to provide the package plant and/or modular system and technical support during the verification testing and study. The manufacturer is also responsible for providing assistance to the field testing organization during operation and monitoring of the package plant or modular system during the verification testing and study.

- **Field Testing Organization** - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the field testing organization is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of a package plant during the intense periods of testing during the study and the tasks required by the Protocol.

- **Modular System -** A packaged functional assembly of components for use in a drinking water treatment system or packaged plant, each part of which provides a limited form of treatment of the feed water(s) and which is discharged to another packaged plant or the final step of treatment.

- **Multistaged Bubble Aeration -** An air-stripping technology that includes the injection of gas bubbles into a column or tank of water to produce intense mixing, resulting in the stripping of gases.

- **NSF** - NSF International, its staff, or other authorized representatives.

- **NSF Equipment Verification Testing Plan** - A specific testing plan for each packaged plant technology application, such as systems employing cation and anion exchange, adsorptive media, reverse osmosis, and air-stripping for the removal of radioactive chemical contaminants. This plan will be developed by NSF for the Manufacturer to assist in development of the FOD for the Verification Testing Project.

- **Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

- **Packed Tower Aeration** – An air-stripping technology that includes the production of thin films or small droplets of water that yield rapid mass transfer, resulting in the stripping of gases.

- **Protocol** - A written document that clearly states the objectives, goals and scope of the study as well as the test plan(s) for the conduct of the study. The protocol shall be used for reference during manufacturer participation in verification testing project.

- **Spray Jet Aeration** - An air-stripping technology that includes an aerator that produces a pressurized water stream that results in a violent mixing of the water and air within the spray jet unit, resulting in the stripping of gases.

- **Testing Organization** - An organization qualified to perform studies and testing of package or modular systems. The role of the testing organization is to ensure that there is skilled operation of a package plant during the intense periods of testing and that all of the tasks required by the Study Protocol for Equipment Verification Testing are performed properly. The Testing Organization is responsible for:

  ⇒ Managing, evaluating, interpreting and reporting on the data produced by the verification testing and study.

  ⇒ Providing logistical support, scheduling and coordinating the activities of all participants in the verification testing and study, i.e., establishing a communications network.

  ⇒ Advising the Manufacturer on feed water quality and test site selection, such that the locations selected for the verification testing and study have feed water quality consistent with the objectives of the Study Protocol for Equipment Verification Testing.

- **Testing Plan** - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the test plan will include detailed instructs for sample and data collection, sample handling and sample preservation, precision, accuracy, and reproducibility goals, and quality assurance and quality control requirements.

- **Testing Laboratory** - An organization certified by a third- party independent organization, federal agency, or a pertinent State regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of package plants and/or modular systems is to analyze the water samples in accordance with the methods and meet the pertinent quality assurance and quality control requirements described in the protocol and test plan field operations document.

- **USEPA** - The United States Environmental Protection Agency, its staff or authorized representatives.

6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of package water treatment equipment utilizing air-stripping technologies that include spray jet, multistage diffused bubble and packed tower aeration. Testing of air stripping equipment will be conducted by a NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a State, NSF, or EPA qualified analytical laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and FOD for removal of radionuclides.

- **Task 1: Characterization of Raw Water** – Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.
- **Task 2: Equipment Verification Testing Plan** – Operate air-stripping and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.
- **Task 3: Operations and Maintenance (O&M)** - Develop an O&M manual for each system submitted. The O&M manual shall characterize air-stripping process design.
- **Task 4: Data Collection and Management** Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 5: Radionuclide Removal -** Evaluate air-stripping technology operations in relation to verified raw water quality.
- **Task 6: Finished Water Quality** – Evaluate the water quality produced by the air-stripping technology as it relates to raw water quality and operational conditions.
- **Task 7: Quality Assurance / Quality Control (QA/QC)** – Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during aeration equipment Verification Testing.
- **Task 8: Cost Evaluation** - Develop O&M costs for the submitted air-stripping technology and package plant.

7.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 8) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the FOD, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the FOD that sufficient water quality data and operational data will be collected to allow estimation of

statistical uncertainty in the Verification Testing data, as described in the "*Protocol for Equipment Verification Testing of for Removal of Radioactive Chemical Contaminants*". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For air-stripping process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the air-stripping module and may require variable strategies in anti-scalant addition and pH adjustment;
- Cold water, encountered in winter or at high altitude locations;
- High concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;
- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing program. Air-stripping testing conducted beyond the required 60-day testing may be used for fine-tuning of air-stripping performance or for evaluation of additional operational conditions. During the testing periods, evaluation of finished water quality can be performed concurrent with air-stripping operation testing procedures.

8.0 TASK 1: CHARACTERIZATION OF RAW WATER

8.1 Introduction

The characterization of raw water quality is needed to determine if the concentrations of radon or other raw water contaminants are appropriate for the use with air-stripping technologies. The feedwater quality can influence the performance of the equipment as well as the acceptance of testing results by Federal and State regulatory agencies.

8.2 Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of radon;
- develop maximum and minimum concentrations for the contaminant; and
- develop a probable percentage of removal necessary to meet the proposed MCL.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

8.3 Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geological Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on the air-stripping equipment that is being tested. The following characteristics should be reviewed and documented:

- Temperature
- pH
- Hardness
- Alkalinity
- Iron and manganese
- Radon
- Volatile Organic Contaminants
- Bacteria
- Other dissolved gases such as CO_2 and hydrogen sulfide

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during the Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

8.4 Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility or historical data. The historical water quality data can be used to determine the suitability of various air stripping technologies for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the verification testing of the aeration equipment.

8.5 Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Capabilities for the removal of radon. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For air-stripping processes, a complete scan of water quality parameters may be required in order to determine pretreatment criteria.

9.0 TASK 2: EQUIPMENT VERIFICATION TESTING PLAN

9.1 Introduction

The equipment verification for air-stripping technologies for radon removal shall be conducted by an NSF-qualified, Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this NSF Plan shall be contracted with a State, NSF, or EPA qualified laboratory. For information on a listing of NSF-qualified FTOs, contact NSF.

9.2 Objectives

The objective of this task is to operate the equipment provided by a Manufacturer, for the conditions and time periods specified by NSF and the Manufacturer.

9.3 Work Plan

9.3.1 Equipment Verification Test Plan

Table 9.1 presents the Tasks that are included in this Plan and will be included in the FOD for radon removal by air stripping technologies. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing.

In the design of the FOD, the FTO shall stipulate which pretreatments are appropriate for application before the selected air-stripping processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 9.1: Task Descriptions

No.	Task	Description
1	Characterization of Raw Water	Obtain chemical, biological and physical characterization of the raw water.
2	Test Plan	Water treatment equipment shall be operated for a minimum of four quarterly testing periods at a minimum of 30 days per test period to collect data on water quality and equipment performance.
3	O&M	Evaluate O&M manual for process.
4	Data Management	Develop data protocol between FTO and NSF.
5	Contaminant Removal	Evaluate radon removal at selected set of operational conditions.
6	Finished Water Quality	Evaluate water quality at selected set of operational conditions.
7	QA/QC	Enforce QA/QC standards.
8	Cost Evaluation	Provide O&M costs of system.

9.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the package water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. In addition, the equipment should not be used for potable water production should a finished water quality parameter not comply with the requirements of the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

9.4 Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one, 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for air-stripping technology performance.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. Air-stripping technology testing conducted beyond the required 60-day testing may be used for fine-tuning of air-stripper performance or for evaluation of additional operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

9.5 Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days. If package water treatment equipment is also operated for potable water production, the data supplied to the FTO shall be evaluated with regard to compliance with National Primary Drinking Water Standards or EPA National Secondary Drinking Water Regulations.

10.0 TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for air-stripping technology to be tested for radon removal shall be included in the Verification Testing evaluation.

10.1 Objectives

The objective of this task is to develop an O&M manual that will assist in operating, troubleshooting and maintaining the air-stripping system performance. The O&M manual shall:

- characterize air stripping technology design;
- outline air stripping procedures;
- air to water ratios;
- cleaning procedures; and
- provide a radon gas safety control plan.

Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

Each specific test plan will include a list of criteria for evaluating O& M information. This shall be compiled and submitted for evaluation by USEPA, NSF and technical peer reviewers. An example is provided in Table 10.2. The purpose of this O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2 O&M Work Plan

Descriptions of air-stripping technology unit process design shall be developed for the removal of radon. Air-stripping technologies shall include the design criteria and equipment characteristics. Examples of information required relative to the air-stripping design criteria and characteristics are presented in Tables 10.3 and 10.4, respectively.

Depending on the raw water quality, chemical cleaning of the air-stripping equipment may be required. Cleaning will be performed as necessary per manufacturer specifications. Packing material for a packed tower aerator may require periodic replacement. Chemical cleaning and material replacement should be noted so that it may be considered for the verification of the equipment.

TABLE 10.1: NSF Operations & Maintenance Manual Criteria - Air-Stripping Package Plants

MAINTENANCE:

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- flow meters
- pumps
- motors
- valves
- air filters
- chemical feeders (pretreatment)
- blowers, jet aerators, course bubble diffusers

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- air-stripping process
- packing material
- piping

OPERATION:

The manufacturer should provide readily understood recommendation for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

Chemical feeders (pretreatment):

- calibration check
- settings and adjustments - how they should be made
- dilution of chemicals - proper procedures

Monitoring and observing operation:

- removal calculations

TABLE 10.1: NSF Operations & Maintenance Manual Criteria - Air-Stripping Package Plants (continued)

OPERATION (continued):

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no pretreatment chemical feed;
- automatic operation (if provided) not functioning;
- no electric power; and

The following are recommendations regarding operability aspects of package plant air-stripping technology processes. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program. During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects.

- are chemical feed pumps calibrated?
- are flow meters present and have they been calibrated?
- are pH meters calibrated?
- can cleaning be done automatically?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Air Stripping Technology Test Plan.

TABLE 10.3: Air-Stripping Technology Design Criteria Reporting Items

Parameter	Unit
Type of unit	
Number of units	
Average flow rate (gpm)	
Maximum flow rate to unit (gpm)	
Minimum flow rate to unit (gpm)	
Air to water ratio	
Surface area at the air/water interface (sf) (Packed Tower)	
Water temperature (^{o}C)	
Air temperature (^{o}C)	
Raw water radon concentration (pCi/L)	
Percent removal of radon (%)	

TABLE 10.4: Air-Stripping Equipment Characteristics

Parameter	Unit
Technology Manufacturer	
Equipment model number	
Diffuser type or packing material type	
Active surface area (sf) (Packed Tower)	
Design hydraulic loading rate (gpm/sf) (Packed Tower)	
Design air to water ratio	
Standard testing removal (%)	
Standard testing pH	
Standard testing temperature (°C)	
Design concurrent flow velocity (fps)	
Maximum flow rate to the unit (gpm)	
Minimum flow rate to the unit (gpm)	
Acceptable range of operating pH values	
Pumping requirements	
Blower Requirements	
Suggested cleaning procedures	
Suggested equipment replacement schedule	
Type of construction	
Estimated Purchase Price	
Other	

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each technology tested

11.0 TASK 4: DATA COLLECTION AND MANAGEMENT

11.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, and manual recording of operational parameters for the air-stripping equipment on a daily basis.

11.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for the NSF for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3 Work Plan

11.3.1 Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of air-stripping equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for three eight-hour shifts per day. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet.) The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2 Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and

operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each air-stripping technology test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state certified or EPA-qualified laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3 Statistical Analysis

For the analytical data obtained during Verification Testing, 95% confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0 TASK 5: RADON REMOVAL

12.1 Introduction

The removal of radon gas from drinking water supplies is accomplished by air-stripping treatment. The effectiveness of radon removal by diffused air and packed tower aeration will be evaluated in this task. Assessment of treatment technologies will be assessed based on percent removal of radon.

12.2 Experimental Objectives

The objectives of this task are to demonstrate:

- appropriate operational conditions for the air-stripping equipment;

- radon removal achieved by the air-stripping technology; and
- necessary cleaning or equipment replacement during process operation.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of air-stripping operation at the operating conditions specified by the Manufacturer, as it pertains to percent removal of radon.

12.3 Work Plan

Determination of ideal aeration operating conditions for a particular water may require as long as one year of operation. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Plan and shall supply written procedures on the operation and maintenance of the air stripping system as outlined previously. For this task the Manufacturer shall specify the operating conditions to be evaluated in the Verification Testing Plan and shall supply written procedures on the operation and maintenance of the air-stripping system. Each set of operating conditions shall be maintained for the 60-day testing period (24-hour continuous operation) for each of four quarterly testing periods. The Manufacturer shall specify the primary hydraulic loading rate at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and "shakedown" of aeration equipment, air-stripping operation should be established at the hydraulic loading condition to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate air-stripping performance under different raw water quality conditions. For aeration technologies, extremes of raw water quality can affect a contaminant's Henry's constant and therefore the air-stripper design. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions. The testing runs conducted under this task shall be performed in conjunction with finished water quality. With the exception of additional testing periods conducted at the Manufacturer's discretion, no additional air-stripping test runs are required for finished water quality.

12.4 Air Stripping Removal Efficiencies

12.4.1 Operational Data Collection

Removal rates of radon from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and finished water flow shall be collected at a minimum of 3 eight-hour shifts per day. Table 12.1 is an example of a daily operational data sheet for an air-stripping system. This table is presented for informational purposes only. The actual forms will be submitted as part of the text plan and may be site-specific.

Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 12.2, except for radon, which will be monitored prior to start-up and then weekly. Power costs for operation of the air-stripping equipment (pumping requirements, chemical usage, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

12.4.2 Raw Water Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of aeration performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished radon concentrations over time for each 60-day test period.
- Plot graph of removal of radon over time for each 60-day test period.

TABLE 12.1: Daily Operations Log Sheet for an Air-Stripping Technology

Date:

Parameter	**Shift 1**	**Shift 2**	**Shift 3**
Time			
Initial			
Air			
Q (cfm)			
T (°C)			
Raw Water			
Q_{raw} (gpm)			
$Radon_{raw}$ (pCi/L)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Finished			
Q_{fin} (gpm)			
$Radon_{fin}$ (pCi/L)			
Removal ($Radon_{raw}$-$Radon_{fin}$)/$Radon_{raw}$) (%)			

TABLE 12.2: Operating and Water Quality Data Requirements for Air-Stripping Processes

Parameter	Suggested Ranking of Importance for Existing Data Packages
Raw Water Flow	3 * Daily
Finished Water Flow	3 * Daily
List Each Pretreatment Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Costs (Kwh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Verification of chemical dosages	Monthly
Feed Water and Finished Water Characteristics	
Radon	Weekly
Temperature	Every two weeks
pH	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
TDS/Conductivity	Every two weeks
Turbidity	Every two weeks
Coliforms	Every two weeks
HPC	Every two weeks

13.0 TASK 6: FINISHED WATER QUALITY

13.1 Introduction

Water quality data shall be collected for the raw and finished water as provided previously in Table 12.2. At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the aeration equipment should be proven and reported in the FOD.

13.2 Objectives

The objective of the entire effort is to verify the Manufacturer claims. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing is provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the FOD.

13.3 Work Plan

The FOD shall identify the treated water quality objectives to be achieved in the Statement of Performance Capabilities of the equipment to be evaluated in the Verification Testing Program. The FOD shall also identify in the Statement of Performance Capabilities the radon removal that shall be monitored during equipment testing. The Statement of Performance Capabilities prepared by the FOD shall indicate the range of water quality under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the Air-Stripping Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Air-Stripping Process Plan is oriented towards removal of radon, the Manufacturer may want to look at the treatment systems removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A State, NSF or EPA qualified analytical laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field are described in Table 13.1. Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the NSF-qualified. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radon	7500-Rn	---
Temperature	2550	170.1
pH	4500-H^+	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Coliforms	9222	---
HPC	9215	---

5) AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998.

6) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

13.4 Analytical Schedule

13.4.1 Removal of Radon

During the steady-state operation of each aeration testing period, radon mass balances shall be performed on the raw and finished water in order to determine the radon removal capabilities of the air-stripping system.

13.4.2 Raw Water Characterization

At the beginning of each aeration testing period, the raw water and finished water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 12.2.

13.4.3 Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of aeration testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radon and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

13.4.4 Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.2 are critical for the Verification Testing Program, as these parameters can substantially influence aeration performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radon
- Water quality and removal goals specified by the Manufacturer

14.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the aeration equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quality data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

14.3.1 Daily QA/QC Verification

- On-line temperature meters (check and verify components)
- On-line pH meters (check and verify components)

14.3.2 Monthly QA/QC Verification

- Pretreatment chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line flow meters/rotometers (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings)
- Air filters (verify good condition of air filters, replace if necessary)
- Diffuser conditions (verify good condition of diffuser, replace if necessary)
- Packing condition (verify good condition of packing, treat or replace if necessary)
- Piping (verify good condition of all piping and connections, replace if necessary)

14.4 Analytical Methods

Use of either bench-top field analytical equipment will be acceptable for the verification testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization

techniques that are approved should be employed. Table 13.3 lists AWWA and EPA standard methods of analysis.

15.0 TASK 8: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of testing air-stripping technologies over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. These equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons if pilot scale units are provided for Verification Testing purposes.

Operation and maintenance (O & M) costs realized in the equipment Verification Test can be utilized for calculating cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical dosage; and
- Equipment replacement frequency.

The O & M costs will vary based on geographic location.

O & M costs should be provided for each air-stripping system that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 15.1.

Table 15.2 Operations and Maintenance Cost	
Cost Parameter	**Specific Utility Values**
Labor rate + fringe ($/personnel-hour)	
Labor overhead factor (% of labor)	
Number of O&M personnel hours per week	
Electric rate ($/kWh)	
Packing Material or Aeration Equipment Replacement (%/year)	
Chemical Dosage (per week)	
O&M Cost ($/Kgal)	

16.0 SUGGESTED READING

APHA, AWWA, and WEF. Standard Methods for the Examination of Water and Wastewater, 18th Edition, Washington D.C.

Atoulikian, Richard G. "Proper Design of Radon Removal Facilities for Cost-Effective Treatment." Journal NEWWA. December 1997.

Cothern, C. Richard, and Rebers, Paul A. Radon, Radium and Uranium in Drinking Water. Lewis Publishers, Chelsea, MI 1990.

Deininger, Rolf A. "Monitoring for Radon in Water." Journal AWWA.

Dixon, Kevin L., Lee, Ramon G., Smith, James and Zielinski, Paul "Evaluating Aeration Technology for Radon Removal." Journal AWWA - Research and Technology, April 1991.

Dixon, Kevin L. and Lee, Ramon G., "Occurrence of Radon in Well Supplies." Journal AWWA - Management and Operations, July 1988.

Dzombak, David A., Roy, Sujoy B. and Fang, Hung-Jung, "Air-Stripper Design and Costing Computer Program." Journal AWWA - Management and Operations, October 1993.

Freiburger, Eric J., Jacobs, Timothy L. and Ball, William P., "Probabilistic Evaluation of Packed-Tower Aeration Designs for VOC Removal." Journal AWWA - Research and Technology. October 1993.

Graves, Barbara, Radon in Ground Water, Lewis Publishers/NWWA Conference, Chelsea, MI 1987.

Hand, David W., Crittenden, John C., Gehin, Joseph L. and Lykins, Jr., Benjamin W., "Design and Evaluation of an Air-Stripping Tower for Removing VOCs from Groundwater." Journal AWWA - Research and Technology, September 1986.

Kinner, Nancy E., Malley, Jr., James P., Clement, Jonathan A. and Fox, Kim R., "Using POE Techniques to Remove Radon." Journal AWWA - Research and Technology, June 1993.

Lowry, Jerry D., "Measuring Low Radon Levels in Drinking Water Supplies." Journal AWWA - Research and Technology, April 1991

Martins, K.L., "Practical Guide to Determine the Impact of Radon and Other Radionuclides on Water Treatment Processes." Water Scientific Tech. 26:1255-1264, Great Britain 1992.

Parrotta, Marc J., "Radioactivity in Water Treatment Wastes: A USEPA Perspective." Journal AWWA - Management and Operations, April 1991.

Pontius, Frederick W. and Paris, David B., "Congress to Decide Fate of Radon Standard." Journal AWWA - Legislation/Regulation, January 1994.

Rand, Peter W., Lacombe, Eleanor H. and Perkins, Jr., W. Dana, "Radon in Homes Following Its Reduction in a Community Water Supply." Journal AWWA - Research and Technology, April 1991.

USEPA. Multimedia Risk and Cost Assessment of Radon. Report to the United States Congress on Radon in Drinking Water. USEPA #811-R-94-001, March 1994.